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APPLIED TECHNOLOGY

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FINAL SUMMARY REPORT

REMOTELY OPERABLE MODULAR SHEAR SYSTEM FOR
SHEARING NUCLEAR REACTOR SPENT FUEL

**CONCEPTUAL DESIGN
FOR**

UNION CARBIDE NUCLEAR CORPORATION
ADVANCED FUEL RECYCLE FACILITY
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENN.
G+W NO. 24017

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Prepared for
OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

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SHEAR
TOOLING
SUBSYSTEMWALL
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SUBSYSTEM

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See Appendix A for Figures and Tables

1.0 SUMMARY

The Remotely Operable Modular Shear System for the Advanced Fuel Recycle Facility concept, as shown in General Arrangement drawing SK-E-3509, is intended to establish a sound technical and design base for further conceptual design and development work.

The close geometry, modularized tooling, and high operating forces all added to the complexity of the design problems. To meet the overall program cost and schedule, the system design had to be limited in the number of conceptual approaches studied. Each individual function throughout the system was selected on the basis of standard engineering and analytical practices which would meet the design criteria. *this was not at 100K why?*

A unique feature of the shear system is the requirement for a removable master tool module and tool submodule assembly. Each tooling submodule is designed specifically to meet the compaction, gagging, and shearing requirements for specific spent fuel assemblies. These submodules are interchangeable within a common master tool module housing. The cross section of the spent fuel assemblies range from a 4.575" hexagonal shrouded to a 8-3/4" square grid-unshrouded. *good!*

The initial engineering effort was directed toward establishing an overall technical approach to be followed during the conceptual design phase. With the technical approach established, a number of interrelated initial design problems had first to be solved.

- A hydraulic force system arrangement with minimum spacing between cylinders
- Readily removable couplings between the force system and associated tooling submodule.
- Couplings to be designed for maximum stiffness and minimum geometry for transmitting closely aligned high tonnage reciprocating forces.

- The applied line of force between each hydraulic force system and its tooling submodule to be selected for minimum twisting moment effects.

- A roller bearing system for each tool submodule and hydraulic stem assembly to provide linear motion for reciprocating operation based on 10 strokes per min. maximum for 4800 consecutive strokes per day for a minimum of one year.

- Long life tool operation under high loads, wear, high temperature and corrosive conditions.

A comprehensive design investigation established that the cylinder arrangement should consist of three - 200 ton, 10 in. dia. tandem cylinders and one 100 ton, 10 in. dia. standard cylinder at 3000 psi operating pressure.

- The shear would be operated by two - 200 ton tandem cylinders in a vertical straddle mode about the horizontal center line of the tooling arrangement.
- The compactor would be operated by one - 200 ton tandem cylinder at the center line of the fuel assembly and tooling arrangement.
- The gag would be operated by one - 100 ton standard cylinder at the center line of the compacted fuel assembly and tooling arrangement.

Table I, Appendix A, shows the various types and sizes of hydraulic cylinders which were investigated.

Figure 1, Appendix A, shows the geometry and layout for the Hydraulic Force System input to the shear tooling.

Gulf + Western were aided by the Franklin Institute Research Laboratory (FIRL) in the investigation and analysis for a bearing system to provide the reciprocating motion for each of the shear tooling and also each of the hydraulic stems passing through the cell wall. FIRL recommended and devised an analytical program for selecting and sizing the roller bearings for the chosen Linear Roller Bearing system. The details of their findings are given in their report in Appendix D.

2.0 INTRODUCTION

This report describes the conceptual design of a Remotely Operable Modular Shear System produced by GULF + WESTERN AD&E center in response to a request by the ORNL Advanced Fuel Recycle Facility (AFRF).

The requirements for the shear system concept, as outlined by ORNL, were as follows:

- . The Modular Shear System is to consist of the Shear Tooling Subsystem, the Wall Enclosure Subsystem, and the Hydraulic Force Subsystem.
- . The tooling is to be designed for assembly into separate modules.
- . The tooling is to be designed to accommodate the various types and sizes of fuel subassemblies.
- . A master tool module is required to house the entire tooling subassembly modules. The master tool module is to be readily inserted and removed from the shear structure surrounding the tooling.
- . The operation of the tooling is to be provided by a hydraulic force system.
- . A system of tie rods shall be used to assemble and structurally integrate each of the subsystem structures to form a unit shear system structure assembly.

This concept represents a basic mechanical and hydraulic shear system based on a defined criteria outlined in Paragraph 3.0 predicated on these requirements. However, the criteria does not include electrical monitoring and control systems, fuel assembly cooling requirements, radiation and air leakage rate through the cell wall.

A complete list of the drawings of the shear system conceptual design is shown on Page iii.

The Remotely Operable Modular Shear System conceptual design as described in this report, along with the associated drawings summarized in Figure 4 and Appendix A, has established the required technical and creative basis for the design and manufacture of an ultimate shear system.

The design philosophy throughout the conceptual program was directed toward providing a basis for developing a sound design criteria and requirements for an advanced conceptual design package. It was not possible to investigate and solve all design problems during this program. Therefore, a method of "flag noting" individual design areas was generated and the resulting comments tabulated on one drawing (SK-E-3507).

3.0 CRITERIA

3.1 System Performance Criteria

The shear system is to demonstrate, under cold work conditions, the actual operation of a unit in a fuel reprocessing facility for the recovery of the reusable fissile and fertile content of spent fuel.

The shear system is to be capable of processing the fuel subassemblies whole or disassembled. This applies to either shrouded or unshrouded fuel whereby the fuel pins only are fed into the shear for compaction, gagging, and shearing.

The shear system shall be capable of shearing fuel in increments between 1/2 in. and 1 in. in length.

The shear system shall have the ability to mechanically process spent fuel subassemblies of various sizes and types, the cross section will range from 4.575" hexagonal shrouded to the 8.75" square unshrouded fuel assembly. The 8.75" square fuel to be process in the diagonally orientation. Figure 7, Appendix A, and drawing SK-E-3511 illustrate. *why?*

The shear system shall be capable of processing 80 core or blanket fuel assemblies per 24 hours which is an average of one fuel assembly every 18 minutes. Figure 3, Appendix A, and drawing SK-E-3513 depict an estimated time and sequence operation for processing one fuel assembly based on assumed times for each event.

The shear system shall be capable of discharging, by gravity, the sheared fuel from the shear.

The shear system shall prevent contamination of the surrounding atmosphere.

The shear system shall be designed for an operational life of 30 years.

3.2 System Function Criteria

3.2.1 Hydraulic Force Subsystem

The system must be capable of producing a maximum force of 400 tons to the shear blade tools, 100 tons to the gag tool and 200 tons to the compactor tool. Each force system shall operate independently.

The line of force from the force system to the tool shall be such as to minimize twisting moment effects on the tool assembly.

The geometry of the hydraulic system cylinder arrangement is to be based on minimum dimensions between each cylinder center line. The overall length of the combined compactor, gag, and shear tools will be based on the force system geometry.

The system shall be required to operate at 10 strokes per min. maximum.

3.2.2 Wall Enclosure Subsystem

This system is to provide the mechanical and structural connection through the cell wall between the hydraulic force system and the shear tooling system and associated structures.

Readily assembled and removable specially designed couplings for connection between the hydraulic rams and wall enclosure stems and shear tooling and stems shall be required.

3.2.3 Shear Tooling

The tooling for mechanical processing of the fuel subassemblies shall consist of a compactor, a gag, and shear blade for both fixed and moving conditions. Their function being as follows:

- The compactor shall first compact the fuel assembly to a required cross-sectional shape over a given length.

- . The fuel assembly is then held between the fixed and moving tooling of the compactor and gag.
- . The protruding portion of the compactor fuel assembly is sheared between the moving and fixed blades of the shear.

3.3 Design Constraints

3.3.1 General

The following design constraints shall be investigated during the follow-on shear system advanced conceptual design. The present conceptual design for the shear system is based solely on initial engineering and design concept techniques to "put together" a basic system from which an advanced conceptual design shall be developed.

3.3.2 Modularization

All equipment in the in-cell part of the shear system shall be modularized to simplify remote handling and maintenance and to minimize size and weight.

All modular components are to meet the following limitations:

- . Weight - 10 tons (5 tons max. where possible).
- . Size - The maximum modular cross section to fit into a 10 ft dia. circle, the maximum length to be 30 ft.

3.3.3 Structural Stiffness

The system structural components shall have a stiffness capable of resisting all combined loads imposed by the mechanical process operation and yet meet the required weight and size limitations.

3.3.4 Material

In-cell components shall be of stainless steel type 304 or 316.

3.3.5 Lubrication

The high in-cell levels of radiation require special consideration for lubrication as follows:

- . Inorganic dry lubricants are acceptable.
- . Lubrication within the cell should be avoided; if it becomes necessary a closed cycle lubrication system shall be provided.
- . Lubricants shall preferably outlast the life of the component(s).
- . Lubricants shall not be allowed to come into contact with the fuel subassembly or the sheared product.

3.3.6 Radiation Sealing and Shielding

- . Components that pass through the concrete cell wall shall be designed to be gastight to allow no leakage of air in excess of 9.1 cfm at a differential pressure of 20 in. H₂O gage. Also, these components shall provide the equivalent radiation shielding density of the concrete wall through which they pass.

3.3.7 Cooling Requirements

- . The shear system shall require no externally supplied cooling.
- . The shear system design shall allow for internally supplied cooling which must be sufficient to remove 12 kw of heat generated by the fuel assembly.

3.3.8 Standardization

Standardized components shall be used throughout the design in accordance with the following:

- . Components shall be interchangeable to the maximum practical extent.
- . The following thread specifications are the only sizes permitted:

1/2"	-	13	UNC	Class 2
1"	-	8	"	"
1-1/2"	-	6	"	"
2"	-	4-1/2	UNC	Class 2
4"	-	4	"	"

3.3.9 Environmental

All in-cell equipment shall be designed for a 30-year life operation under the following environmental conditions:

- . Temperature - 70 to 115°F
- . Operating Pressure
-1 to -4 in. H₂O gage with respect to the area outside of
the cell
- . Atmosphere

Essentially pure nitrogen or air with up to 100 PPM H₂O.

3.3.10 Process

Sheared Fuel

The length of the sheared fuel shall be between 1/2 in. and 1 in. according to the chosen incremental feed setting. Each end of the sheared fuel tubing shall be at least 75% open to prevent trapping of fuel within the tubing.

Sheared Fuel Discharge

The sheared fuel shall be discharged by gravity.

Gas Enclosure

A gas enclosure shall be required to contain the sheared fuel-rod gases and fuel particles. The gas enclosure shall be equipped with an exhaust system.

3.3.11 Monitoring and Control

All operations of the shear system shall be remotely controlled and monitored. The design shall include the necessary sensing and measuring devices for normal operation, malfunction and detection feedback.

4.0 PREFERRED SYSTEM DESCRIPTION

4.1 Overall System

The overall shear system conceptual design is depicted in the general arrangement drawing No. SK-E-3509 and its associated drawings listed on page iii.

The shear system consists of three separate but integrated subsystems:

- . The Shear Tooling Subsystem located inside the cell.
- . The Wall Enclosure Subsystem located within the cell wall.
- . The Hydraulic Force Subsystem located outside the cell wall.

The combined subsystem assembly is aligned so that the motion of the force system and shear tooling system is at 90 degrees to the wall of the cell.

The hydraulic force system is connected to the shear tooling through the cell wall by the wall enclosure subsystem. This is accomplished with the use of stems or columns which are easily disconnected from the tooling employing a specially designed coupling.

A system of tie rods is used to assemble structurally the three subsystem structures to form the unit shear system assembly.

The three subsystem structures are connected by four tie rods and compression members under a total pre-tensioned load of 1000 tons. The shear tooling and hydraulic force subsystems are supported by the cell foundation. Through this design the total weight of the shear system is supported by the cell foundation eliminating structural support effect on the cell wall, therefore, minimizing system damage in the event of an earthquake.

4.2 Hydraulic Force Subsystem

The hydraulic force subsystem is designed to provide a maximum total force of 700 tons to the shear tooling, 200 tons for fuel assembly compaction, 100 tons for gagging of the compacted fuel and 400 tons for fuel shearing.

Fig. 1, Appendix A, and drawing No. SK-E-3498 illustrates the hydraulic cylinder arrangement to apply the high tonnage force to each tool and ram assembly. This arrangement is based on the use of 10 in. dia. hydraulic cylinders for each tool with the maximum allowable hydraulic working pressure of 3000 psi.

Tandem type (twin piston) cylinders are used to provide the required force on the compactor and shear tooling. A standard (single piston) cylinder provides the force required for the gag tool. Two tandem type cylinders are required for the fuel shearing operation. A total of four 10 in. dia. rear head flange mounted hydraulic cylinders constitute the combined hydraulic force system cylinder arrangement.

The hydraulic force subsystem consists of three separate systems designed to provide independent operation for each of the shear tools. Each hydraulic system is designed for a maximum operating rate of 10 strokes per minute.

Drawing No. SK-E-3513 and Figs. 2 & 3, Appendix A, show schematic diagrams for the hydraulic flow and control system and time and sequence operation for the shear tooling. Appendix B gives the analysis for estimating the pump and motor requirements.

The flow diagram includes an error sensing and correction circuit designed to maintain exact synchronization of the two cylinders powering the fuel shearing operation.

Drawing No. SK-E-3511 shows the interface and connection between the system hydraulics and each tool of the shear tooling assembly, and including the working strokes and hydraulic piston travel positions for the operation and maintenance of the shear tooling.

Drawing No. SK-3497 shows the design concept for the structure to house the hydraulic cylinder assemblies. The structure consists of two compartments longitudinally aligned one behind the other. The front compartment is designed to

house and react the combined tandem cylinder forces for the 400 ton shear and 200 ton compactor. This reaction member or platen separates the two compartments and also allows the gag hydraulic intermediate stem to pass through to the rear compartments. The rear compartment houses and reacts the single standard cylinder force for the 100 ton gag. This force is reacted by a platen which forms the rear end frame of the overall structure. The front end frame is a simple plate supporting the front bay tandem hydraulic cylinders.

4.3 Wall Enclosure Subsystem

This subsystem, shown on drawing No. SK-E-3485, provides the mechanical and structural connection between the hydraulic force subsystem located outside of the hot cell, and the shear tooling subsystem inside the hot cell. This subsystem provides the means for supporting, guiding, lubricating, and radiation attenuation for each of the four hydraulic stems connecting the hydraulic force subsystem to the individual compactor, gag, and shear tooling.

Atmospheric radiation sealing of each stem is achieved by securing to each stem and wall enclosure interface a cylindrically shaped metal bellows. The bellows are designed to allow for a continuous maximum working stroke of 10 inches and a full 24 in. cylinder travel to allow for equipment assembly and maintenance.

The basic design feature of the bellows is a series of flat upset discs of welded construction and capable of long life operation. The material is a non-ferrous and non-corrosive metal. The physical connection between the wall enclosure stems, the hydraulic force system and shear tooling is by means of specially designed couplings (drawing No. SK-E-3494).

The stems provide the means for transmitting high compressive forces to the tooling. The stiffness of each stem has been maximized to ensure no buckling should the stems be subjected to excessive force input. This has been accomplished by choosing a large nominal stem diameter coupled with a "step-up" of this diameter

through the wall enclosure structure. Another feature is inserting replaceable longitudinal wear shoes for mating with the roller bearings to prevent surface wear along each stem.

4.4 Wall Enclosure Structure

Drawing No. SK-3477 describes the system structure. The structure consists of a center solid casting 44 in. dia. x 66 in. lg. closed in at each end by rectangular plates 4 in. thick. Tie rod compression members connect between the two end plates in four places dimensioned in a rectangular pattern. These compression members extend beyond the end plate located at the cell wall cold zone surface, a distance of 75 inches, to interface with the hydraulic force system structure. This provides space between the hot cell wall and hydraulic force system structure for hydraulic stem coupling and operation and also accessibility for repair and maintenance for the wall enclosure system.

The end plate located at the cell wall hot zone interfaces directly with the shear system structure. Assembly of this structure within the hot cell wall is critical in establishing alignment between the shear structure subsystem and hydraulic force subsystem.

The center casting is machined to provide for the assembly and support of each of the four hydraulic stems passing through the cell wall. The center lines of the stems are aligned with and match to the center lines of the hydraulic force system cylinder arrangement. The linear bearings, lubrication, and metal bellows sealing required for the operation of these stems are shown on Drawings SK-E-3437 and SK-E-3438.

Each stem is supported by three double length bearing assemblies spaced 120 degrees apart with one bearing positioned at the top along the length of the stem. The linear bearing assemblies are secured to the wall enclosure structure by means of machined dovetailed slots running along the length of stem bores within

the structure cast body. The linear bearing assemblies are positioned and secured longitudinally by a gland housing and metal bellows mounting flange at the cold zone cell wall interface.

Each linear bearing assembly consists of (15) 1 in. dia. x 1 in. lg. rollers assembled in line along the length of rail of channel section geometry with a conical dovetail base. One end of a bearing rail assembly is extended for attachment to a similar bearing assembly, making a combined bearing assembly length of 25.25 inches.

As the wall enclosure system is an integral part of the cell wall the design life of the equipment is based on the required 30 year operational life of the cell.

Analysis for the wall enclosure subsystem components is shown on the following pages in Appendix C:

Stem Linear Bearings Pages 2, 10, 11 & 12

Buckling of Stepped Stems Page 25

4.5 Shear Tooling Subsystem

The shear tooling subsystem encompasses all shear system functions and operations inside the hot cell. The interface between the wall enclosure subsystem and the shear tooling subsystem is the coupling connection at the stems. Figure 4, Appendix A, and drawing No. SK-E-3494 shows this subsystem. Supporting analysis for this subsystem concept appears in Appendix C.

4.6 Tooling and Stem Couplings

Drawing No. SK-E-3494 shows the couplings between the stems and the moving tool rams. The width profile of the couplings are determined by the closeness of the shear and gag tooling and by the bearing area required in the "dog bone" shape couplings. The depth of the couplings were based on providing a safe

required cross sectional area for transmitting the direct high tonnage force within the allowable compressive yield stress of the material. There are four couplings: one each for the compactor and gag, and two for the shear.

The design philosophy for the couplings were:

- . Capable of transmitting high tonnage hydraulic forces to the tooling.
- . Be accessible and readily inserted or removed.
- . Be designed for replaceability in preference to maintenance.

The design for the couplings differ in one aspect. The shear is considered the most important of the three operation, therefore, no lost motion must exist between the stem and shear tool ram. The longitudinal fit of the coupling(s) is designed for a tight wedge fit, the inclined surfaces of the coupling end faces are designed to prevent upward force vector effects under horizontal compressive force conditions.

The compactor tool geometry, by definition, generates large twisting moments throughout its tooling which must not be allowed to feed back through the wall enclosure stem and system. The longitudinal fit for this coupling is therefore designed to be slightly loose.

The gag tool geometry is designed theoretically for no twisting moment effects, and therefore, like the compactor, is designed for a loose longitudinal fit.

The lateral fit of all couplings is designed for ease of assembly and removal.

4.7 Shear System Tooling

The tooling for the shear system consists of both moving and fixed tools. The fixed tooling provides the support and positioning for the fuel subassemblies and also the reaction forces (for compaction, gagging, and shearing) to the applied moving tool forces.

The conceptual design for the forming and cutting tool profiles are not considered to be a part of the shear system. However, it was essential to generate realistic profiles (based on ORNL & G+W combined design and experimental experience) to establish a design base for:

- . Feeding, compacting, gagging, and shearing of spent fuel subassemblies as based on distorted fuel subassemblies shown in Figures 5 & 6, Appendix A, and Drawing No. SK-C-3397.
- . Establishing maximum operating strokes to accommodate the two types of fuel subassemblies representing the smallest (AF hexagonal shrouded) and the largest (LWR 8-3/4 sq. unshrouded) to be accommodated by the shear are based on design analysis shown in Figure 7, Appendix A, and Drawing No. SK-C-3511.
- . Establishing force and twisting moments and their effects on the tooling and surrounding structure are based on the compactor tooling which, by geometry and the required compaction force, produce the maximum moment conditions.
- . The linear roller bearing, size, type, and configuration required for the tooling operations.

4.8 Tool Submodules

Each (moving) tool is housed within a module which can readily be removed and assembled to the master tool module which houses all the tooling--both fixed and moving.

The close geometry of the tooling dictated the modular concepts. The compactor comprises a single module and the gag and moving shear blade together comprise another single module, thus all tooling is housed in two separate modules.

Each tool module assembly consists of the tool, tool ram body, linear bearing assembly, and module housing. The module housings are firmly secured within the master tool module.

For each moving tool module subassembly the tool ram body, the linear bearing assembly, and the module housing is of standard design to accommodate each size of tool required to match the various types of fuel assemblies, also for

the fixed tooling (SK-E-3406). Each tool holder and support is designed to accommodate each size of tool required to match the various types of fuel assemblies.

The reciprocating motion of the tooling is based on "X" type or vertical type linear bearings mounted between the ram body and module housing.

These bearings are critical components performing a number of functions:

- . Provide linear motion for reciprocating tool operation.
- . Resist and transmit high level loads from the tooling through to the master tool module and then to the shear structure.
- . Control tool ram deflections to prevent twisting moment feed-back through the couplings and hydraulic cylinders.

Franklin Institute Research Laboratories (FIRL), specialists in the field of linear bearings, provided G+W with comprehensive computer programs (Report F-C4846, Appendix D) to determine bearing size, type, and geometry for the shear tooling and hydraulic stem slide operating conditions.

4.9 Compactor Submodule

Of the three tool operations (compaction, gagging, and shearing) compaction of the fuel subassembly generates the largest twisting moment effects. Also, since the compactor tooling is somewhat removed from the closely aligned gag and shear tooling, the compactor tooling was developed as a separate tool submodule.

The developed concept for the compactor submodule is shown on Drawing No. SK-E-3508. This concept evolved around computer analysis (see Appendix C & D) to determine the type and geometry for a linear bearing system assembly to meet the operating and functional conditions. Drawing No. SK-E-3508 shows two types of bearings - upright and inclined ("X" type). The upright bearings are for resisting large horizontal side forces generated by the applied 200 ton direct force through the offset compactor tooling. The "X" type bearings are for resisting vertical forces generated by the tooling rocking motion during the compaction operation.

The size and geometry of the ram body to which the linear bearings are assembled, along with consideration for the compaction tool geometry (for various fuel subassembly sizes) was then temporarily established (the final length of the ram body was determined by hydraulic stroke and travel position Drawing No. SK-E-3511). This, in turn, defined the geometry for the submodule housing, and compactor submodule.

Also shown is the method of assembly and securing the compactor submodule to the master module.

4.10 Gag and Shear Submodule

The development for the compactor submodule with the results from the associated linear bearing computer analysis, Appendix D, established the basis for the gag and shear combined submodule. Drawing Nos. SK-E-3520 and SK-E-3446 show the conceptual design for the gag and shear submodule. This combined submodule, housing two separate and individual tool operations and functions in close proximity to one another, presented a unique situation. This required solution of the following interrelated major problem areas:

- . Tool ram body shapes and lengths.
- . Tool ram working strokes (for all fuel subassemblies).
- . Shear tool ram strength and stiffness to offset 400 ton direct force input.
- . Couplings and hydraulic stem interface positions relative to the overhead crane and associated tooling.
- . Determining the minimum working space dimension between the fully forward position of the tool and ram bodies and the fully retracted position of the decoupled hydraulic stems.
- . Determining the maximum required length of hydraulic cylinder(s) to encompass all shear tooling operations and estimated equipment handling space requirements.

The final established distance of 10'6" between the fuel feed center line and the hot cell wall evolved from the above design investigations.

4.11 Master Tool Module Assembly

The master tool module assembly concept provides a unique self-contained replaceable tooling package feature for the shear system. It increases substantially the flexibility of the mechanical reprocessing operation within the hot cell, and can also remove the burden of maintenance and repair from the shear operation area to a remote area.

The development of the tooling submodules, along with the associated conceptual design solutions, established the concept basis for the master tool module and assembly.

The initial concept for the modularization of the shear tooling was based on a separate design of a master tool module and tool submodule assembly for processing each individual type fuel subassembly.

During the conceptual design for the tooling submodules it became evident that a standard design for the tooling submodules and master tool module would be desirable. This standard module design approach was adopted and is based on compacting, gagging, and shearing of the largest fuel assembly under the longest pressure stroke and maximum force conditions. This was also used as a basis for the linear bearing analysis (Appendix D).

The master tool module as described in Drawing Nos. SK-E-3482, SK-E-3510 and SK-E-3480, with the exception of the fixed and moving compactor, gag, and shear tool, can be used for processing all the fuel subassemblies described in this report for accommodation within the shear system.

In addition, the shear tooling, both fixed and moving, may use the largest shear blade for all shearing operations. However, for the compaction and gag tools which have specially shaped profiles particular to individual fuel subassemblies, replacement is required.

The design approach for the module housing was based on combined direct and twisting moment forces from the total submodules. Under worst case conditions these forces are considered to occur simultaneously at the point of shearing:

- . Compacted fuel subassembly under combined direct forces of compaction (200 tons) and gagging (100 tons) in position for shearing.
- . Shear blade in contact with the fuel subassembly under a 400 ton direct force (200 tons from each stem) suffers pressure loss in one stem hydraulic cylinder (see Appendix C, pages 8 & 9).

The module housing Drawing No. SK-E-3482 was designed to absorb the force and moment effects with a minimum of deflection ensuring maximum transmittal to the shear structure assembly. Detailed analysis for the conditions stated are shown in Appendix C, page 13. General arrangement Drawing No. SK-E-3509 describes a step-by-step sequence for insertion and removal of the master tool module assembly to the shear structure and associated hydraulic stem system.

The lifting device secured to the module housing is to be positioned to ensure that the master tool module assembly suspended from the O.H. crane hook is vertically aligned for smooth entrance and exit to the shear structure.

4.12 Shear Structure Assembly

The shear structure assembly shown on Drawing Nos. SK-E-3469 and SK-E-3470 is designed to provide the structural containment, packaging, and total enclosure of the shear operation within the cell. Three major components form the basis for the assembly:

- . Shear Structure
- . Gas Enclosure
- . Gravity Chute

4.13 Shear Structure

The shear structure is basically a thick wall; thin bottom rectangular open box design, one end of which interfaces directly with the wall enclosure system structure. The top of the structure being open. The cell wall end of the structure allows the four hydraulic stem and metal bellows assemblies of the force system to extend into the cell and operate within the confines of the shear structure. The outer end of the structure is designed to receive and structurally secure the master tool module assembly containing each of the three compactor, gag, and shear tools and associated submodules. Assembly and disassembly of the shear tooling and the hydraulic force system is by means of an overhead crane and associated handling equipment operating inside the top opening of the structure. The design of the structure also provides for the assembly of the tie rod system used to react the high tonnage forces generated by the shear operation, through the shear system structure.

4.14 Gas Enclosure

The gas enclosure, as shown on Drawing No. SK-E-3469, is seated on the top surface of the shear structure completely covering the rectangular opening in the structure immediately above the shear tooling and hydraulic force input operation.

The sealing interface between the gas enclosure and the shear structure is obtained by compressing a continuous rectangular "O" ring seal under the gravitational weight of the gas enclosure assembly.

The enclosure is connected to the shear structure along one edge by a hinged assembly aligned normal to the cell wall and positioned on the opposite side of the structure to the disassembly and feed system interface.

The enclosure is operated through an angle of 90 degrees about the hinge horizontal and vertical center lines using a remotely operated air actuator system.

The operation of the enclosure is toward the disassembly and feed system.

5.0 SPECIFIC DESIGN FEATURES TO BE EVALUATED

The design philosophy throughout this conceptual program was directed toward providing the best possible technical base for the follow-on conceptual designs in the development of a remotely operable module shear system.

It was not possible to investigate and solve all the design problems that evolved during this program. Therefore a method of "Flag Noting" individual design areas was initiated and the resulting comments tabulated on drawing (SK-E-3507).

This approach summarizes the major design areas that require further consideration and possible solution before proceeding with future design concepts.

- Alignment of all three subsystems and associated structures.
- Moving and fixed blade clearance adjustment feature.
- Maintenance and replacement of the tool submodule linear bearing assemblies.
- Force system couplings
- Linear bearings, roller and rail assemblies
- Compactor, gag and shear blade tool and tool profile design
- Compactor geometry for all fuel subassemblies
- Compactor, gag and shear moving tool submodules
- Shear structures interface with master tool module assembly
- Hydraulic stem anti-rotational guide feature
- Metal bellows radiation seals concept
- Replacement of metal bellows within hot cell
- Sheared fuel gravity chute unjamming feature
- Synchronization of the shear twin cylinders and stems

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The Remotely Operable Modular Shear System Conceptual Design described in this report, along with the associated drawings summarized on page ¹¹¹¹ represents the initial approach for the creation of an original design of a Shear and Tooling System for mechanical reprocessing spent nuclear fuel subassemblies,

The concept consists only of a basic design for a mechanical and Hydraulic Shear System, however, it does not include Electrical Monitoring and Control System requirements and other associated system requirements stated in this report.

The main technical approach for the initial Shear System Concept was to produce a conservative design based on the solution and development of each individual system function and operational requirement. The Design Constraints set forth in Section 3.3 were used as target goals.

6.2 Recommendations

6.2.1 Weight

A weight-to-stiffness design optimization versus cost of manufacture should be considered a necessary part of the design for the Shear System.

6.2.2 System Alignment

Foundation interfaces and support for the shear and hydraulic structure, along with an approved method of assembly and alignment for the complete shear system, should be thoroughly investigated.

6.2.3 System Expansion

Longitudinal growth of the combined shear system structure, due to the effects from both temperature and stress conditions, should be investigated.

6.2.4 Radiation Shielding

The design of the wall enclosure system structure requires coordination with the A&E engineering contractor involved in the design of the hot cell.

This is to ensure adequate sealing against air leakage through the wall and also prevention of radiation streaming.

6.2.5 Shear Blade Clearance Adjustment

The design of the adjustment feature should be based on the following major considerations:

- Blade clearance
- Wear
- Misalignment

All design facets of the adjustment mechanism should allow for operator remote handling.

APPENDIX A

LIST OF CONCEPTUAL STUDY DRAWINGS

FIGURE NOS. 1 TO 7

TABLE NO. 1

LIST OF CONCEPTUAL STUDY DRAWINGS

Along with the final conceptual drawings as summarized in the report, the following represents the total number of conceptual drawings produced for the conceptual design of the Remotely Operable Modular Shear System;

<u>DRAWING NO.</u>	<u>STUDY CONCEPT TITLE</u>	<u>REFERENCE</u>
SK-E-3212	TWIN 200 TON SHEAR STD. COM. CYLS. VERTICAL STRADDLE ON SHEAR	HYDRAULIC FORCE SYSTEM
SK-E-3213	TWIN 200 TON SHEAR TANDEM COM. CYLS. NO. TOOL HOLDER	
SK-E-3214	TWIN 200 TON SHEAR TANDEM COM. CYLS. WITH TOOL HOLDER	
SK-E-3215	TWIN 50 TON GAG SPEC. CYL. CASTING VERTICAL STRADDLE ON GAG	
SK-E-3216	IN-LINE HORIZONTAL CYLS. SPEC. CYL. CASTING TANDEM CYLINDERS	
SK-E-3217	TWIN 50 TON GAG SPEC. CYL. CASTING TANDEM CYLINDER	WALL ENCLOSURE SUBSYSTEM
SK-E-3309	WELDMENT ROUND WALL ENCLOSURE END VIEW GEOMETRY	
SK-E-3310	WELDMENT ROUND WALL ENCLOSURE CROSS SECTION	
SK-E-3311	RECTANGLE WALL ENCLOSURE END VIEW GEOMETRY	
SK-E-3312	STEMS 8 IN. DIA. & 6 IN. DIA. THRU-WALL	
SK-E-3313	HYDRAULIC CYLINDER GEOMETRY AND FLANGE MOUNTING	
SK-E-3314	10 IN. TANDEM CYLINDER OUTLINE DIMENSIONS 200 TON	
SK-E-3315	7 IN. TANDEM CYLINDER OUTLINE DIMENSIONS 100 TON	
SK-E-3316	HYDRAULIC CYLINDER ARRANGEMENT MOUNTING PLATE & TIE RODS	

<u>DRAWING NO.</u>	<u>STUDY CONCEPT TITLE</u>	<u>REFERENCE</u>
SK-E-3466	WALL ENCLOSURE & STEM BEARING, SEAL BELLOWS INTERFACE	} WALL ENCLOSURE SUBSYSTEM
SK-E-3428	WALL ENCLOSURE & STEM BEARING - ROLLER - CASTING	
SK-E-3326	TOOL MODULE - SHEAR, GAG & COMPACTOR 'X' TYPE LINEAR BRG.	} SHEAR TOOLING SUBSYSTEM
SK-E-3330	COMPACTOR SLIDE BRG. & WORKING TRAVEL	
SK-E-3331	REMOTE OPERATION FOR SHEAR, GAG & COMPACTOR	
SK-D-3332	SHEAR COUPLING	
SK-D-3333	GAG COUPLING	
SK-C-3334	METHOD FOR FEEDING FUEL ASSY. INTO TOOL ASSY. FOR THREE STAGE COMPACTION	
SK-E-3339	SHEAR & GAG SECTION BEARING CONCEPT (12 IN. TOOL)	
SK-E-3381	COMPACTOR SUBMODULE INTERFACE WITH SHEAR TOOL MODULE	
SK-E-3341	COMPACTOR SLIDE BEARING MOUNTING & RAM CONCEPT	
SK-E-3425	WALL ENCLOSURE & STEM BEARING - ROLLER - WELDMENT	
SK-E-3218	METHOD FOR COUPLING HYDRAULIC FORCE TO MOVING SHEAR BLADE WITH OR WITHOUT TOOL HOLDER	
SK-D-3382	COMPACTOR TOOL HOLDER	
SK-E-3448	PRELIMINARY FLOOR PLAN LAYOUT	
SK-D-3398	FUEL BUNDLE COMPACTED	
SK-D-3400	SHEAR TOOLING TRAVEL & PROFILE	
SK-E-3421	FIXED BLADE REMOVAL (PLAN VIEW)	
SK-E-3422	FIXED BLADE REMOVAL (FRONT VIEW)	
SK-C-3430	ADJUSTABLE SHEAR BLADE CONCEPT	
SK-E-3442	GENERAL ARRANGEMENT	

DRAWING NO.STUDY CONCEPT TITLEREFERENCE

SK-D-3449

SHEAR STRUCTURE

SK-E-3427

SHEAR & GAG RAM IN ONE SUBMODULE

SK-D-3451

BASIC TOOL MODULE

SK-D-3547

SHEAR TOOL HOLDER COUPLING

SK-D-3548

COMPACTOR & GAG TOOLING PROFILES

SK-D-3549

STEM COUPLING CRANE HOOK

SK-D-3550

COMPACTOR TOOL HOLDER

SK-D-3551

TOOL HOLDER

SK-D-3552

COMPACTOR TOOL HOLDER
SEPARATE WEDGE LOCK

SK-C-3553

STEM COUPLING

SK-D-3554

COUPLING HOOK

SHEAR
TOOLING
SUBSYSTEM

HYDRAULIC FORCE SYSTEM ARRANGEMENT
(Also See Dwg. SK-E-3498)

(Same as Fig. 1 in Appendix

FIGURE 1

STRADDLED SHEAR
PUMP SERVO CONTROL

GAG

COMPACTOR

SEE APPENDIX B FOR PUMP & MOTOR ESTIMATE

HYDRAULIC FORCE SYSTEM FLOW DIAGRAM
(3000 psi Working Pressure)
Also see Dwg. SK-E-3513

FIGURE 2

ESTIMATED TIME & SEQUENCE DIAGRAM
 FOR
 HEXAGONAL (SHROUDED) FUEL ASS'Y & 8 3/4 x 8 3/4 (17x17 TUBES)
 UNSHROUDED FUEL ASS'Y WHOLE ELEMENT SHEARING.
 (Also see Dwg. SK-E-3513)

DRAWING TREE SUMMARY
(Also see Dwg. SK-E-3544)

FIGURE 4

HEXAGONAL SHROUDED SPENT FUEL SUBASSEMBLY
DISTRIBUTION CHARACTERISTICS

FIGURE 5

DIMENSIONAL CONSIDERATIONS — ON THE ROTATION OF THE FUEL ASSBLY — DUE TO THE POSSIBLE 4" MAX. ECW.

RE: ISOMETRIC SKETCH → CROPPING DATA for 766J584 FUEL ASSBLY & 766J586 RADIAL BLANKET ASSEMBLY

RE: SKETCH — 4" BOW IN 14FT. FUEL ASSBLY — E.M. 7-20-76

ASSUME BOW LINE IS FORMED BY 2 CIRCULAR ARCS PASSING THRU THE POINT OF MAX. BOW AND HAVING THEIR CENTERS ON THE LINE PERPENDICULAR TO THE POINT OF MAX. BOW.

x IS THE RADIAL DISPLACEMENT OF THE CL AT THE LID BRG.
 θ IS THE $\angle$ BETWEEN BOW CL AND THE $\perp$ TO THE CL OF LID BRG.

$$4(2R_1 - 4) = (93)^2$$

$$8R_1 - 16 = 8649$$

$$R_1 = \frac{8649 + 16}{8} = 1083"$$

$$4(2R_2 - 4) = (75.0)^2$$

$$8R_2 - 16 = 5625$$

$$R_2 = \frac{5625 + 16}{8} = 705$$

$$x_1 = 4 - [R_1 - \sqrt{(R_1)^2 - (93.0 - 11.5)^2}]$$

$$x_1 = .93$$

$$\sin \theta_1 = \frac{93.0 - 11.5}{1079} = .0755$$

$$\sin \theta_1 = 4.3^\circ$$

$$x_2 = 4 - [R_2 - \sqrt{(R_2)^2 - (9.5 + 121.0 - 93.0)^2}]$$

$$x_2 = 3.00$$

$$\sin \theta_2 = \frac{(9.5 + 121.0 - 93.0)}{705} = .0532$$

$$\sin \theta_2 = 3.0^\circ$$

HEXAGONAL SHROUDED SPENT FUEL SUBASSEMBLY
 DISTORTION ANALYSIS

FIGURE 6

COMPACTION AND SHEAR PROFILES
FOR
SHROUDED AND UNSHROUDED
SPENT FUEL SUBASSEMBLIES

(Also see Dwg. No. SK-E-3511)

CONCEPT	CYLINDER TYPE	CYLINDER DIA.	FORCE SYSTEM CONCEPTS					STEM DIA.	PSI
I SK-E-3212	Standard Commercial	14"	<u>Straddled Shear</u>						3000
	"	10"	Shear Blade	Two Rams	200 ton each			8	
	"	14"	Gag	One "	100 "	"	"	5½	
	"	14"	Compactor	One "	200 "	"	"	8	
II & IIA SK-E-3218	Tandem Commercial	10	<u>Straddled Shear</u>						3000
	"	7	Shear Blade	Two Rams	- 2 x 100 ton each			8	
	"	10	Gag	One "	- 2 x 50 "	"	"	6	
	"	10	Compactor	One "	- 2 x 100 "	"	"	8	
III	Triple Commercial	9	<u>Straddled Shear</u>						3000
	"	6	Shear Blade	Two Rams	- 3 x 70 ton each			8	
	"	9	Gag	One "	3 x 35 "	"	"	6	
	"	9	Compactor	One "	3 x 70 "	"	"	8	
Remarks - Stem Size - No change Cylinder Size - No significant change									
IV	Standard Special Design	20	<u>In Line (Horizontal) Hydraulics</u>						3000
	"	10	Shear Blade	One Ram	400 tons			10½	
	"	14	Gag	One "	100 "			6	
	"	14	Compactor	One "	200			8	
Remarks - Tandem Cylinder Concept evolved from this and applied to Concept I to create Concept II & IIA									
V SK-E-3215	Standard Special Design	20	<u>Straddled Gag</u>						3000
	"	7	Shear Blade	One Ram	400 tons			10½	
	"	14	Gag	Two Rams	50 tons each			6	
	"	14	Compactor	One Ram	200 "			8	
Remarks - Cross Head Beam large section geometry									
VI SK-E-3216	Tandem Special Design	14	<u>In Line (horizontal) Hydraulics</u>						3000
	"	7	Shear Blade	One Ram	- 2 x 200 tons			10½	
	"	10	Gag	One "	2 x 50 "			6	
	"	10	Compactor	One "	2 x 100 "			8	
Remarks - No significant reduction in cylinder spacing stem dias. No change in dias.									
VII SK-E-3217	Tandem Special Design	14	<u>Straddled Gag</u>						3000
	"	4	Shear Blade	One Ram	- 2 x 200 tons			10½	
	"	10	Gag	Two Rams	2 x 50 each			6	
	"	10	Compactor	One Ram	x x 100			8	
Remarks - Large stem dia. for shear No possible configuration									
VIII	Triple Special Design	12	<u>In Line (horizontal) Hydraulics</u>						3000
	"	6	Shear Blade	One Ram	- 3 x 135 tons			10½	
	"	9	Gag	One "	3 x 35 "			6	
	"	9	Compactor	One "	3 x 70 "			8	
Remarks - No significant change from Concept III									

TABLE I

APPENDIX B

HYDRAULIC FORCE SYSTEM
PUMP AND MOTOR REQUIREMENTS

HYDRAULIC FORCE SYSTEM

ESTIMATED PRESSURE REQUIREMENTS

CONSIDERING HYDRAULIC SYSTEM FOR SHEARING OPERATION ONLY

TOTAL EST. WT OF MOVING PARTS = 8000 LBS

MAX APPLIED FORCE FOR ONE CYL ONLY = 200 TONS

TOTAL FORCE ON SHEAR TOOL FOR TWO CYL = 400 TONS

CONSIDERING ONE CYLINDER HYDRAULICS (10" PRESS STROKE)

FORCE BALANCE

$$F_p = P + Ma + F_f$$

$$F_f = \mu N = .1 \times 8000^{\text{lb}}$$

$$P = 200 \text{ TONS}$$

$$M = \frac{W}{g} = \frac{8000}{386.4}$$

VELOCITY

$$V = at \quad V = \text{AV. VEL} \times 2$$

$$V = 2 \left[\frac{s}{t} \right] = 2 \times \frac{10''}{4} = 5$$

$$\text{VEL} = 5 \text{ IN/SEC}$$

ACCELERATION

$$a = \frac{V}{t} = \frac{5}{1/4}$$

$$\text{ACC.} = 20 \text{ IN/SEC}^2$$

FORCE

$$F_p = P + Ma + F_f$$

$$400,000^{\text{lb}} + \left[\frac{8000}{386.4} \times 20 \right] + 800$$

$$F_p = 401,214 \text{ LBS}$$

HYD PRESS REQ'D

$$= \frac{F_p}{\text{PISTON AREA}} = \frac{401,214}{.7854(10^2 - 5.5^2) + .7854 \times 10^2}$$

PISTON AREA

$$.7854(10^2 - 5.5^2) + .7854 \times 10^2$$

$$= 3010 \text{ PSI}$$

$$\text{SYSTEM CONCEPTUAL DESIGN PRESSURE} = 3000 \text{ PSI}$$

BASED ON 10 STROKES/MIN
MAX - 4 SEC FORWARD
2 SEC RETURN

VELOCITY DIAGRAM
(ASSUMED)

HYDRAULIC FORCE SYSTEM

ESTIMATED MOTOR AND PUMP CAPACITIES

FOR ALL HYDRAULIC REQUIREMENTS FOR THE
SHEAR, GAG, AND COMPACTOR TOOLING

THE FOLLOWING CALCULATIONS ARE BASED ON THE
THE SHEAR BLADE TWIN CYLINDER HYDRAULIC SYSTEM

CONSIDERING ONE (TANDEM) CYLINDER

FLOW = VELOCITY x PISTON AREA

$$Q = 5 \text{ in/sec} \times [(.7854 \times 10^2) + (.7854(10^2 - 5 \frac{1}{2}^2))]$$

$$= 667 \text{ cu in/sec}$$

$$\text{TWO CYLINDERS} = 2 \times 667 = 1334 \text{ cu in/sec } (0.772 \text{ cu ft/sec})$$

$$= .772 \times 448.831 \text{ GPM}$$

$$\text{PUMP SIZE} = Q = 347 \text{ GPM}$$

MOTOR SIZE

$$\text{HP} = \frac{\text{PRESS} \times \text{GPM} \times 5.83}{10^4 \times 0.80 (\text{EFFICI})}$$

$$= \frac{3000 \times 347 \times 5.83}{10^4 \times 0.8} = 758.6$$

$$\text{HP} = 760$$

THE ABOVE IS CONSIDERED TO BE CONSERVATIVE
AS IT IS BASED ON A MAXIMUM OPERATING VELOCITY
OF 5 in./sec WHICH IN TURN IS BASED ON A MAXIMUM
WORKING STROKE OF 10 INCHES.

APPENDIX C

ORNL REMOTELY OPERABLE MODULAR SYSTEM

CONCEPTUAL DESIGN PRELIMINARY ANALYSIS

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24017

DATE

2-2-78

1. Summary

Engineering analyses of the concepts generated for the shear design were made. The objectives of these analyses were to determine the validity of the concepts, and to seek out problem areas in various major components. Approximate sizes and sections were determined by simplified relationships if the concepts were considered valid. Alternative approaches were studied if serious problems were found in the original concepts.

Limited by the budget for analytical work, the analysis applied only to the major components which were considered as permanent structure, and the components whose dimensional changes would effect the basic design of the structure. The components whose dimensional changes would not effect the other components were not evaluated.

For the concept work, the shear was designed on a very conservative basis. In the subsequent design stage, more precise analyses will be performed to determine the size of each component and its performance.

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2. Tool Bearings and Through-the-Wall Stem Bearings

All these bearings are considered to be major components. The through-the-wall bearings are part of the permanent structure. The tool bearing sizes are determining factors for the tool structure. Therefore, an accurate bearing analysis is required to predict the bearing life. Since bearing design requires empirical data, such as working stress level, the analysis was subcontracted to The Franklin Institute Research Laboratories.

FIRL has been involved in bearing design work for industry and government. It is considered reputable in the field of bearing design. A bearing design computer program, which had been developed by FIRL, was available to calculate the load and stress on each roller of the bearing and to predict the bearing life. SEE APPENDIX D FOR THE FRANKLIN INSTITUTE RESEARCH LABORATORIES (FIRL) LINEAR ROLLER BEARING SYSTEM ANALYSIS

2.1 Bearing Design Computer Programs:

REPORT.

FIRL uses a small Data 20 computer whose FORTRAN contains some statements and symbols which are not acceptable to the Super FORTRAN of the large computer. Corrections were made to make the program run at our terminal. Modifications were also made to facilitate the running. The computer program after modification is called "BEAR". It is run in binary coded program under the name "CBEAR". The background information relating to the bearing design computer program is described in FIRL's report and is attached.

2.2 Tool Bearings:

Reference Drawings SK-E-350B and SK-E-3446

For applied Forces see Fig. 1 and SK-E-349B

2.2.1 Gag Bearing

Loading:

200,000 lb. in z direction

Assuming uniform distributed reaction and
no reaction at the taper:

Max. Moment = $200,000 \times 1" = -200,000$ in-lb.
about Y axis (Right hand rule)

HYDRAULIC FORCE SYSTEM ARRANGEMENT
(Also See Dwg. SK-E-3498)

FIGURE 1

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Computer Results:

Max Hertz stress on one roller: 92,360 psi

Allowable Hertz stress: 300,000 psi

Bearing system Life

For 6½" full power stroke 14 Years

" 1" " " " infinite life

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2.2.2 Compactor Bearing:

Compacting load: The approximation of compacting load by calculation is unrealistic. The buckling load in radial direction of each fuel rod housing can be approximated. The buckling load of the hexagonal fuel assembly housing is not easy to handle. As the fuel assembly housing collapses, the free space between the fuel rods is reduced and the wire wrapping around the fuel rod is compressed. The bulk modulus of the fuel is not known.

It was learned that ORNL data from compacting a 4.575" hexagonal fuel assembly with 1" width gag indicated a linear relationship between load and Travel as shown in the following figure.

Compacting fuel assembly
with an 1" Gag.

this linear load and travel relationship
was chosen for the following calculations:

Loading : Assuming load distribution as follows:

$$P = \frac{400,000}{\cos \theta} = 416,666 \text{ lb.}$$

$$P \sin \theta = 116,666 \text{ lb.}$$

in - x direction

$$\text{Moment} = 116,666 \times 25.375$$

$$= -2.96 \times 10^6 \text{ in-lb.}$$

(right hand rule)

Bearing coordinate is the same as Gag Bearing.

Computer results :

Max. Hertz stress on one roller : 185,000 psi

Allowable Hertz stress : 300,000 psi

Bearing life : 1.84 years

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2.2.3 Shear Bearing:

Loading: There are two moments, one about Y axis due to the shear cutting edge .375" offset from the load, the other about X axis due to pressure differential between two hydraulic cylinders.

The moment about Y axis (same coordinate as the other Bearing systems)

$$= 800,000 \times .375" = 300,000 \text{ in} - \text{lb.}$$

The 800,000 lb load is from two 200 Tons cylinders.

The moment about X axis depends on the pressure differential between two cylinders:

<u>pressure differential</u>	<u>Moment</u>
0	0
40 psi	138,720 in - lb.
80 "	276,640 " "
120 "	414,960 " "
160 "	553,280 " "
200 "	691,600 " "
1063 "	3,684,000 " "

These moments could be either positive or negative, depending on which cylinder has higher pressure, and will coexist with the moment about Y axis.

Computer Results:

<u>Pressure differential</u>	<u>Bearing life</u>
0	2.83 Years
40 psi	.75 Years
80 "	.125 "

Roller Hertz stress:

Max roller Hertz stress is 216,000 psi at 212 psi pressure differential. The allowable stress is 300,000 psi

2.2.4 Enlarged Shear Bearing:

The bearing in section 2.2.3 does not have adequate life, because 80 psi pressure differential is only 3% of working hydraulic pressure. For subsequent design consideration, increase the roller size to 2" dia x $2\frac{1}{2}$ " without lengthening the submodule by reducing the number of rollers.

Computer Results:

<u>Pressure differential</u>	<u>Life</u>
0	34.5 Years
40 psi	13.8 "
80 "	4.7 "
120 "	2.0 "
160 "	1.0 "

Roller Hertz Stress:

Max roller Hertz stress is 282,000 psi (allowable 300,000 psi) at 1000 psi pressure differential between cylinders. Therefore, the bearing can stand the initial shock of 1000 psi pressure differential.

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2.3 Through-The-Wall Stem Bearing

The basic design for each Through-The-Wall Stem Bearing is the same, except the stem diameter and the load for each bearing is different.

2.3.1 Gag Stem Bearing

Loading: There are two loads on the bearing: stem weight and moment. For the moment, it is assumed that there is a possible misalignment of $\frac{1}{400}$ the length of the stem. The figure $\frac{1}{400}$ of the length, has been suggested by many strength of Materials books for the calculation of the buckling load of a slender column.

weight = 2158 lb. in Y direction

Moment = $\frac{164.75}{400} \times 200,000 = 82,375$ in-lb
in any direction. Several computer runs indicated that a moment about the Y axis gave higher stress and shorter life than that of a moment about the X axis. Therefore, in the following calculations, the moments were about the Y axis.

Computer Results:

Life	infinite
stress	low.

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2.3.2 Shear Stem Bearing:

It was suggested a more rigid coupling be used for the shear. Therefore the moment of the tool is $.375" \times 400,000 \text{ lb} = 150,000 \text{ in-lb}$, and may be transmitted to the stem through the - wall bearing. This moment is about Y axis.

Loading:

Stem weight 3024 lb.

Moment $\frac{168}{400} \times 400,000 \text{ lb}$

$= 168,000 \text{ in-lb}$ in any direction

Max. moment is the combination of this moment with the tool moment

$= 168,000 + 150,000$

$= 318,000 \text{ in-lb}$ about Y axis

Computer Results:

Bearing life: 6 Years with $6\frac{1}{2}"$ full power stroke. It is understood that, in actual operation, only a portion of the stroke is at full power.

Therefore, it is considered adequate.

Roller Hertz stress: low.

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2.3.3 Compacter Stem Bearing :

Loading :

stem weight 3194 lb.

Moment = $\frac{168}{400} \times 400,000 = 186,000$ in - lb.

in any direction. It was found that this moment about the Y axis gave minimum life.

Computer Results :

Bearing life 60 Years

Roller stress 10W.

3. Submodule Analysis:

The submodules were analyzed to determine the sections to be able to resist the load and the moment from the bearings.

3.1 Compactor Submodule:

The load on the bearing.

Reference Drawing SK-E-3427
SK-E-3441

$$\tan \theta = \frac{2.0625}{14} = .14732$$

$$\theta = 8.38^\circ$$

Assuming the load distribution as shown

$$R_1 = \frac{400,000}{\cos 8.38^\circ} = 404,300 \text{ lb}$$

$$R_x = 400,000 \text{ lb}$$

$$R_y = 400,000 \tan 8.38^\circ = 58,900 \text{ lb}$$

Moment M applied to the bearing

$$M = 400,000 \times 1.33 + 58,900 \times 21.96 = 1,826,000 \text{ in-lb}$$

These loads and moment have to be resisted by the submodule.

Since the four bearings are identical and both the load and the moment are applied at the centroid of the bearing system, it is assumed that the load and the moment are equally distributed to the bearings.

Load distribution: q lb/in.

Due to moment $\frac{1826000}{4} = 453000$

$$q_1 = \frac{453000 \times 6}{24.5} = 4258 \text{ lb/in.}$$

Due to R_y 58900 lb

$$q_2 = \frac{58900}{4 \times 24.5} = 595 \text{ lb/in.}$$

combined q

$$= q_1 + q_2 = 5123 \text{ lb/in. max.}$$

The required sections were determined by examining a submodule section of 1" width at the max. q and analyzing it by considering it as a two dimensional structure using the existing structural analysis program GENSAP (developed by Control Data Corporation). The information regarding the use of Program GENSAP is fully described in "GENSAP", Static Analysis of Elastic Structure User Information Manual, by Control Data Corporation.

The reactions on the submodule :

Due to 45° roller angle

$$P_n = \frac{5123}{\cos 45^\circ} = 7245 \text{ lb.}$$

$$P_x = P_y = 5123 \text{ lb.}$$

$$R_x = 10246 \text{ lb.} \quad R_y = 10246 \tan 45^\circ = 10246 \text{ lb.}$$

The structure is divided into 12 elements as shown in the following sketch. The complete computer input and output of the final acceptable sections are attached in the Appendix A. A summary of the computer results is listed in the following page.

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Summary of Element stresses

Element No.	Joint No.	Axial stress psi	Bending stress psi	Combined stress psi
1	1	1903	-20831	22734
	2	1903	-14095	15998
2	2	9622	267	9889
	3	9622	-414	10036
3	3	1903	14164	16067
	4	1903	20883	22786
4	4	2732	-7189	9921
	5	2732	-8533	11265
5	5	-1413	-6196	-7609
	6	-1413	-3645	-5059
6	6	-2732	13628	-16360
	7	-2732	-17434	-20166
7	7	.15	9236	9236
	8	.15	124	124
8	9	1875	666	2541
	8	1875	-779	2654
9	10	-.15	-9254	-9255
	9	-.15	-106	-106
10	11	-2732	-13646	-16378
	10	-2732	17452	-20185
11	12	-1413	6191	-7605
	11	-1413	3650	-5064
12	1	2732	7171	9903
	12	2732	8551	11283

Allowable stress: 100,000 psi

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3.2 Gag and shear submodule:

The gag and the shear share the same submodule. It is analyzed the same way as the compactor submodule. The load and moment resisted by this submodule are different from the compactor submodule and are as follows:

The moment loading:

1. From the Gag

$$\text{Moment} = 200,000 \times .94 = 188,000 \text{ in-lb.}$$

$$\frac{188,000}{2} = 94,000 \text{ in-lb./bearing.}$$

$$q = \frac{94,000 \times 6}{24.52} = 940 \text{ lb./in.}$$

2. From the shear

Moment due to load offset

$$\text{Moment} = 800,000 \times .38 = 304,000 \text{ in-lb.}$$

$$\frac{304,000}{2} = 152,000 \text{ in-lb/bearing.}$$

$$g = \frac{152,000 \times 6}{24.52} = 1570 \text{ lb/in.}$$

In addition to the above moment, there could be another moment due to the pressure differential between the two hydraulic cylinders. Before the bearing design program was developed, it was estimated that this moment amounts to 1,068,000 in-lb

$$g = \frac{1,068,000 \times 6}{24.52} = 10670 \text{ lb/in}$$

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$$P_{13x} = 1570 \text{ lb.}$$

$$P_{13y} = 1570 \text{ lb.}$$

$$M_{13} = 1570 \times 1.63 = 2478 \text{ in. - lb.}$$

$$P_{16x} = 1570 \text{ lb.}$$

$$P_{16y} = -1570 \text{ lb.}$$

$$M_{16} = 2478 \text{ in. - lb.}$$

condition 2.

$$P_{10y} = 10670 \text{ lb.}$$

The complete computer input and output of the final acceptable sections for condition 1 and condition 2 are attached in Appendix B and C respectively. A summary of computer results is listed in the following pages.

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Summary of Element stresses

Condition 1 Repetitive load: Gag and shear loading

Element No.	Joint No.	Axial stress psi	Bending stress psi	Combined stress psi
1	1	-138	-2759	-2897
	2	-138	-3049	-3187
2	2	672	-240	913
	3	672	232	905
3	3	1093	-557	1597
	4	1093	-863	1903
4	4	672	361	1033
	5	672	-368	1040
5	5	-138	3658	-3796
	6	-138	3392	-3530
6	6	499	-1298	1797
	7	499	2610	3109
7	7	258	-698	956
	8	258	851	1109
8	8	-93	-261	-354
	9	-93	0	-93
9	8	420	-500	920
	10	420	384	804
10	10	420	-384	804
	11	420	279	699
11	11	812	-1045	1857
	12	812	259	1072
12	12	-115	-228	-343
	13	-115	-3634	-3749
13	13	645	-83	727
	14	645	81	725
14	14	1719	-574	2293
	15	1719	-646	2366
15	15	645	91	735
	16	645	-93	738

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Condition 1 continues

Element No.	Joint No.	Axial stress psi	Bending stress psi	Combined stress psi
16	16	-115	3810	-3925
	17	-115	-671	-786
17	17	808	763	1572
	18	808	218	1027
18	18	448	-67	515
	19	448	429	878
19	19	-65	113	-178
	20	-65	0	-65
20	19	503	-2559	3062
	21	503	1739	2242
21	21	503	-1739	2242
	1	503	1056	1559

Allowable stress : 100,000 psi

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Condition 2 Non-repetitive load: load due to
Pressure differential between two hydraulic cylinders.

Element No.	Joint No.	Axial stress psi	Bending stress psi	Combined stress psi
1	1	-686	17340	-18026
	2	-686	-16014	-16701
2	2	-686	16014	-16701
	3	-686	-15601	-16288
3	3	-1061	37368	-38369
	4	-1061	36705	-37767
4	4	-686	-15349	-16036
	5	-686	15733	-16420
5	5	-686	-15733	-16420
	6	-686	17355	-18043
6	6	115	-6644	6259
	7	115	13168	13283
7	7	59	-3523	3582
	8	59	4286	4346
8	8	-3826	203	-4030
	9	-3826	0	-3826
9	8	-67	-4560	-4627
	10	-67	-3111	-3177
10	10	-67	3111	-3177
	11	-67	-2747	-2814
11	11	-129	10269	-10399
	12	-129	-7551	-7680
12	12	398	6636	7034
	13	398	-6022	6420
13	13	398	6022	6420
	14	398	-5877	6275
14	14	1062	41772	42833
	15	1062	41446	42508
15	15	398	-5831	6229
	16	398	5987	6385

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Condition 2 Continues

Element No.	Joint No.	Axial stress psi	Bending stress psi	Combined stress psi
16	16	398	-5987	6385
	17	398	6488	6886
	17	129	-7383	7512
17	18	129	3985	4114
	18	71	-1226	1298
18	19	71	-28	99
	19	0	90	90
19	20	0	0	0
	19	-114	-837	-952
20	21	-114	-3240	-3355
	21	-114	3240	-3355
21	1	-114	-6638	-6753

Allowable stress 100,000 psi

4. Buckling of Stepped Stems :

considered as column and determine the equivalent length.

$$P_{cr} = \frac{\pi^2 E \cdot I}{l^2}$$

Equivalent length

$$P_{cr} = \frac{\pi^2 E I_1}{l_1^2} = \frac{\pi^2 E I_2}{l_2^2}$$

$$\frac{I_1}{l_1^2} = \frac{I_2}{l_2^2}$$

$$\therefore l_1^2 = \frac{I_1}{I_2} l_2^2 = \left(\frac{d_1}{d_2}\right)^4 l_2^2$$

$$l_1 = \left(\frac{d_1}{d_2}\right)^2 l_2$$

A. For the shear

Equivalent length of middle section :

$$l = \left(\frac{8}{9}\right)^2 \times 96 = 75.85"$$

$$\text{Total } l = 34 + 75.85 + 60 = 169.85"$$

$$S_{yp} = \frac{P}{A} \left(1 + \frac{e c}{r^2} \sec \frac{l}{2r} \sqrt{\frac{P}{EA}}\right) \quad \text{Ref. see p. 2}$$

n = factor of safety

P = load = 400,000 lbs.

r = radius of gyration
 $= \sqrt{\frac{I}{A}} = \frac{d}{4}$

$$E = 27,500,000 \text{ psi}$$

$$e = .375 + \frac{d}{400} \text{ (see section 2.3.1)}$$

$$A = \frac{\pi}{4} d^2$$

A small computer program has been developed to determine the Yield Point as a function of Factor of Safety. (Appendix P) The computer output is summarized as follows:

<u>F.S.</u>	<u>Y. P.</u>
2	40,292 psi
2.5	58,163 "
3	84,615 "
3.5	130,160 "

B. For the Gog.

Equivalent length of 8" dia. to 6"

$$= 96 \times \left(\frac{6}{8}\right)^2 = 54"$$

total length of equivalent 6" diameter

$$= 27 + 54 + 141 = 222"$$

computer output

<u>F.S.</u>	<u>Y. P.</u>
2	21,046 psi
2.5	35,937 "
3	77,730 "

C. For the compactor

Equivalent length of 9" to
8" dia.

$$L = 96 \left(\frac{8}{9} \right)^2 = 75.85"$$

Total length of equivalent 8" diameter
= 44 + 75.85 + 60 = 179.85"

Computer Output

<u>F.S.</u>	<u>Y.P.</u>	
2	31445	psi
2.5	45188	"
3	67945	"
3.5	117,669	"

* Elements of Strength of Materials by
S. Timoshenko and G. H. MacCullough
page 310 Equation 148

$$S_{yp} = \frac{\pi P}{A} \left(1 + \frac{ec}{r^2} \sec \frac{L}{2Y} \sqrt{\frac{\pi P}{EA}} \right)$$

5. Fixed Tool Reaction Analysis:

The compactor: To determine the horizontal component introduced due to the angle of the compactor, the following equations are established.

$\alpha_2 \ll \alpha_1 \gg \alpha_3$
(because of the roller bearing.)
 $\tan \alpha_2$ and $\tan \alpha_3$ can be ignored
where α_1, α_2 & α_3 are friction angles

$$\sum F_x = 0 \quad -N_1 \sin \theta + N_1 \tan \alpha_1 \cos \theta + N_2 = 0$$

$$N_2 = N_1 \sin \theta - N_1 \tan \alpha_1 \cos \theta$$

$$\sum F_y = 0 \quad P - N_1 \cos \theta - N_1 \tan \alpha_1 \sin \theta = 0$$

$$N_1 = \frac{P}{\cos \theta + \tan \alpha_1 \sin \theta}$$

The minimum $N_2 = 0$

$$0 = N_1 \sin \theta - N_1 \tan \alpha_1 \cos \theta$$

$$N_1 \sin \theta = N_1 \tan \alpha_1 \cos \theta$$

$$N_1 \tan \theta = N_1 \tan \alpha_1$$

$$\theta = \alpha_1 \quad \text{for } \alpha_1 \geq \theta$$

$$\sum F_x = 0 \quad P_1 + P_2 \tan \alpha_1 + N_1 \tan \alpha_1 \cos \theta - N_1 \sin \theta = 0$$

$$\sum F_y = 0 \quad P_2 - N_1 \tan \alpha_1 \sin \theta - N_1 \cos \theta = 0$$

$$P_2 = N_1 (\tan \alpha_1 \sin \theta + \cos \theta)$$

$$P_1 = N_1 \sin \theta - P_2 \tan \alpha_1 - N_1 \tan \alpha_1 \cos \theta$$

$$= N_1 \sin \theta - N_1 (\tan \alpha_1 \sin \theta + \cos \theta) \tan \alpha_1$$

$$- N_1 \tan \alpha_1 \cos \theta$$

$$= N_1 (\sin \theta - \tan^2 \alpha_1 \sin \theta - 2 \tan \alpha_1 \cos \theta)$$

$$= N_1 \sin \theta \left(1 - \tan^2 \alpha_1 - \frac{2 \tan \alpha_1}{\tan \theta} \right)$$

$$\text{For } P_1 = 0 \quad \alpha_1 = 5.27^\circ$$

The above analysis indicated that:

- the horizontal component of the movable tool is 0 if $\alpha_1 \geq 0$
- The horizontal reaction of the fuel $P_1 = 0$ if $\alpha_1 \geq 5.27^\circ$.

The coefficient of friction between the fuel and the compactor is believed to be around .5 or higher thus $\alpha_1 \geq 26.56^\circ$. Therefore the horizontal components are absorbed by the friction and are ignored in the analysis. In other words, no horizontal component is introduced to the fixed tool.

6. Tool Module Housing Back side plate :

considered as a rectangular plate with Fixed Edges

Reference Drawing
SK-E-3482

All the available equations for rectangular plates are derived either for uniformly distributed load over the entire area or a concentrated load applied at the center. For the purpose of determining the feasibility, the derivation of concentrated load at the center is adapted. It is understood that the relationships derived for concentrated load at the center would be conservative to be used for our loading, which is distributed at several locations.

To determine the approximate plate thickness, the following calculations are made based on different sources :

A. Based on "Advanced Mechanics of Materials" by
F.B. Seely and A.O. Smith

page 244

Section 74 stress in rectangular plate; concentrated
load at center and Fixed edged -

Table 10 (page 243)

Moment in span b

At center of Edge $\frac{\frac{1}{6}P}{1+\frac{1}{3}\alpha^2}$

where $\alpha = \frac{b}{a} = 1$ for a rectangular

∴ moment at the center of the Edge

$$= \frac{1}{8} P = .125 P$$

At center of slab for load on central
Area $a_0 = .25 b$

$$\text{Moment} = .158 P \quad \text{for } \alpha = 1 \text{ \& } \mu = 0$$

Max deflection

$$C(1-\mu^2)(Pb^2/Et^3)$$

where μ = Poisson's ratio = .25 assumed

$$E = 27.5 \times 10^6$$

b = length of side 32"

t = plate thickness

P = total load in lbs.

$$= 700 \times 2000 = 1,400,000 \text{ lb}$$

$$C = \text{a constant} = \frac{1.087}{1+.3} \text{ for rectangular}$$

It is seen that the max. moment occurs at the center of the slab

$$= .158 \times 1,400,000 = 221,200$$

Choose stainless steel which has a yield stress of 90,000 psi with a factor of safety of 5 or design stress = 18,000 psi

$$18000 = \frac{221200 \times 6}{1 \times t^2}$$

$$t^2 = \frac{221200 \times 6}{18000} = 73.733$$

$$t = 8.58"$$

Max deflection

$$= \frac{.087}{1.3} (1.25^2) \frac{1,400,000 \times 32^2}{27,500,000 \times 8.58^3}$$

$$= .0051"$$

B. Based on "Formula for Stress & Strain" by Roark 4th Edition

page 393 Case 8b

Assuming $r_0' = 8"$ Poisson's ratio $\nu = .25$

$$\sigma_0 = \frac{3W}{2\pi t^2} \left[(1 + \nu) \ln \frac{2b}{r_0'} + \beta_1 \right]$$

$\beta_1 = -.238$ for rectangular

$$t^2 = \frac{3 \times 1,400,000}{2 \times \pi \times 18000} \left[(1 + .25) \ln \frac{2 \times 32}{8} - .238 \right]$$

$$t = 9.36"$$

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$$\text{for } t = 8.58$$

$$\sigma_b = 21441 \text{ psi}$$

check deflection for $t = 8.58$ "

$$y = \frac{\alpha W b^2}{E t^3}$$

$$= \frac{.0611 \times 1,400,000 \times 32^2}{27,500,000 \times 8.58^3}$$

$$= .005 "$$

The stress is a little higher than that calculated by the formula in Seely & Smith book, while the deflection are very close. It is believe that a 8" plate is conservative.

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7. The compactor coupling

Reference Drawing
SK-E-3508

Section A-A

$$\text{direct compression} = \frac{400,000}{5.6 \times 12} = 5952 \text{ psi}$$

$$\text{Bending stress} = \frac{74000 \times 6.24 \times 6}{12 \times 5.6^2} = 7362 \text{ psi}$$

$$F = \frac{74000 \times 8}{7.225} = 81938 \text{ lb.}$$

Section B-B

$$\text{Bending stress} = \frac{81938 \times 1.7875 \times 6}{12 \times 2^2} = 8066 \text{ psi}$$

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Section C-C

$$\text{Bending stress} = \frac{81,938 \times 1.9 \times 6}{12 \times 2.225^2} = 15723 \text{ psi}$$

Assuming the wedge preloaded to 220 Tons

Direct tensile

$$= \frac{220 \times 2000}{2 \times 2.225 \times 12} = 8240 \text{ psi}$$

$$\text{Combined} = 15723 + 8240 = 23963 \text{ psi}$$

Section D-D

$$\text{Bending stress} = \frac{74000 \times 1.8 \times 6}{12 \times 2.225^2} = 13453 \text{ psi}$$

$$\text{Allowable stress} = 100,000 \text{ psi}$$

8.0 Shear Blade and Associated Components :

8.1 Shear Blade :

Reference Drawing SK-E-3511

Material : AISI M2 Tool steel

Hardness : 65 Rc

Compressive strength 470,000 psi

tensile strength 350,000 psi

The load distribution on the blade is complicated due to its alligator teeth and the random shape of the fuel assembly as a result of the compacting process. To be on the safe side, it is assumed that the load is concentrated at the corner as shown.

Stress at section A-A

Direct compression

$$= \frac{400 \times 2000}{2.12 \times} = 26,954 \text{ psi}$$

Bending Moment

$$= 400 \times 2000 \times 1.06 = 848,000 \text{ in-lb.}$$

Bending stress

$$= \frac{848,000 \times 1.06 \times 6}{\times 2.12^2} = 85,714 \text{ psi}$$

Combined stress

$$= 112,668 \text{ psi compressive}$$

$$= 58,760 \text{ psi tensile.}$$

8.2 Shear Blade Holder and Dog Bone Coupling:

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Stress at section A-A

Section Properties

Element 1 = Element 3

$$A_1 = 7 \times 3.75 = 26.25 \text{ in}^2 = A_3$$

$$y_1 = 1.875 = y_3$$

$$I_1 = \frac{7}{12} \times 3.75^3 = 30.76$$

Element 2

$$A_2 = 14 \times 1.63 = 22.82 \text{ in}^2$$

$$y_2 = 1.815$$

$$I_2 = \frac{14}{12} \times 1.63^3 = 5.05$$

Combined Elements 1, 2 & 3

$$A = 75.32$$

$$y = \frac{2 \times 26.25 \times 1.875 + 22.82 \times 1.815}{75.32} = 1.554$$

$$I = 2 [I_1 + A_1 (y_1 - y)^2] + I_2 + A_2 (y - y_2)^2$$

$$= 66.93 + 17.51 = 84.44$$

Moment

$$= 400 \times 2000 \times 2.196 = 1.757 \times 10^6 \text{ in-lb.}$$

Bending stress

$$= \frac{1,756,000 \times 2.196}{84.44} = 46,708 \text{ psi compressive}$$

$$= \frac{1,756,000 \times 1.554}{84.44} = 32,316 \text{ psi tensile}$$

Contact stress between Shear Blade
and Blade Holder

Assuming uniformly distributed

$$\text{compressive stress} = \frac{400 \times 2000}{14 \times 2.12} = 26,954 \text{ psi}$$

combined with compressive stress due
to bending

$$= 26,954 + 46,708 = 73,662 \text{ psi}$$

Stress at section B-B

$$I = \frac{5.5}{12} (6.5^3 - 5^3) = 68.58$$

$$\text{Moment} = \frac{400}{2} \times 2000 \times 3.375 = 150,000 \text{ in-lb.}$$

bending stress

$$= \frac{150,000 \times 3.375}{68.58} = 7108 \text{ psi}$$

Considered the Holder as a beam simply supported at ends and partial uniform loaded.

$$R_1 = R_2 = 400,000 \text{ lbs.}$$

Max. moment at center

$$= 800,000 \times \frac{13}{26} \left(6 + \frac{14 \times 13}{2 \times 26} \right) = 3,200,000 \text{ in-lbs}$$

Section at center

section properties

Element 1

$$A_1 = 6.5 \times 2.75 = 17.875 \text{ in}^2$$

$$y_1 = 1.375$$

$$I_1 = \frac{6.5}{12} \times 2.75^3 = 11.26$$

Element 2

$$A_2 = \frac{3.75 + 6.5}{2} \times 2.75 = 14.09$$

$$y_2 = 2.75 \frac{6.5 + 2 \times 3.75}{3(6.5 + 3.75)} + 2.75$$

$$= 4.0$$

$$I = \frac{2.75^3}{36} (6.5^2 + 4 \times 6.5 \times 3.75 + 3.75^2)$$

$$= 8.669$$

Element 3

$$A_3 = 4.5 \times 3.75 = 16.875$$

$$y_3 = \frac{4.5}{2} + 2.75 + 2.75 = 7.75"$$

$$I_3 = \frac{3.75}{12} \times 4.5^3 = 28.48$$

Element 4

$$A_4 = 8 \times 1.5 = 12 \text{ in}^2$$

$$y_4 = 4 + 4.5 + 2.75 + 2.75 = 14$$

$$I_4 = \frac{1.5}{12} \times 8^3 = 64$$

Combined

$$A = 17.875 + 14.09375 + 16.875 + 12 \\ = 60.84 \text{ in}^2$$

$$y = (17.875 \times 1.375 + 14.09375 \times 4.00 \\ + 16.875 \times 7.75 + 12 \times 14) / 60.84 \\ = 6.24$$

$$I = 11.26 + 17.875 (6.24 - 1.375)^2 \\ + 8.669 + 14.09 (6.24 - 4.00)^2 \\ + 28.48 + 16.875 (7.75 - 6.24)^2 \\ + 64 + 12 (14 - 6.24)^2 \\ = 1367.2$$

$$C_1 = 6.24$$

$$C_2 = 11.78$$

BY

H. S. C.

PROJECT

24017

DATE

10-14-77

Bending stress

$$S_t = \frac{3,800,000 \times 11.76}{1367.2} = 32,685 \text{ psi tensile}$$

$$S_c = \frac{3,800,000 \times 6.24}{1367.2} = 17343 \text{ psi comp.}$$

Allowable 100,000 psi

$$\theta = \frac{1}{48EI} \left[-8R_1 l^2 + W \left(\frac{8d^3}{l} - \frac{2bc^2}{l} + \frac{c^3}{l} + 2c^2 \right) \right]$$

where $l = 26$

$$W = 800,000$$

$$a = 6$$

$$b = 20$$

$$c = 14$$

$$d = 13$$

$$E = 27.5 \times 10^6 \text{ psi}$$

$$\theta = -\frac{1.1103}{I} \text{ rad.}$$

To bend the θ back with M_e at
Each ends

$$\theta = \frac{M_e l}{3EI} + \frac{M_e l}{6EI} = \frac{M_e l}{2EI}$$

$$\frac{1.1103}{I} = \frac{M_e l}{2EI}$$

$$M_e = \frac{1.1103 \times 2 \times 27.5 \times 10^6}{26}$$

$$= 2,775,750 \text{ in-lb.}$$

This is too high a moment to be resisted by the Dog Bone and the sections in the holder which contains the Dog bone.

To make sure that the blade holder is freely supported, a cylindrical contact surface on the Dog Bone and a flat surface slot on the shear Blade Holder is suggested as shown in the following sketch.

A flat surface on the Blade Holder will introduce some moment which will be transferred to the Dog Bone and finally to the stem. The magnitude depends on the radius of curvature on the Dog Bone and the rigidity of the Blade holder.

$$\theta = \frac{.841212}{I} \text{ rad.}$$

considered constant I

$$0 + \frac{3.75}{12} 18^3 = 1822 \text{ for the holder}$$

$$\theta = .0004616 \text{ rad.}$$

$$= .026^\circ$$

$$P = 200 \times 2000 / \cos .026^\circ = 409,000 \text{ lb.}$$

$$P \tan \theta = 184 \text{ lb.}$$

$$\text{Let } R = 5''$$

$$\text{load/unit length} = \frac{409,000}{5''} = 80,000 \text{ lb./in.}$$

contact stress:

$$R_1 = 5'' \quad R_1' = \infty$$

$$R_2 = \infty \quad R_2' = \infty$$

$$B = \frac{1}{2R_1} = .1 \quad A = 0$$

$$\Delta = \frac{1}{\frac{1}{2R_1} + \frac{1}{2R_2}} \left[\frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2} \right]$$

$$\mu_1 = \mu_2 = .3 \text{ assumed}$$

$$E_1 = E_2 = 27,500,000$$

$$\Delta = .000000662$$

$$b = \sqrt{\frac{29\Delta}{\pi}} = .1836$$

BY

PROJECT

DATE

contact stress

$$\sigma_2 = \frac{b}{\Delta} = 277,329 \text{ psi} \text{ seems to be acceptable}$$

GENSAP PROGRAMS

- A. Input and Output of GENSAP Program on Compactor Submodule Analysis
- B. Input and Output of GENSAP Program on Gag and Shear Submodule, Condition I
- C. Input and Output of GENSAP Program on Gag and Shear Submodule, Condition II
- D. Yielding Point of Material Required as a Function of Factor of Safety

FIN2
OLD
RUN

NET 060037

PLEASE SIGN ON--KC,N1886KQ

77/12/20. 09.16.50.

EASTERN CYBERNET CENTER SN166 NOS

1.0/411.399.0-0

PASSWORD

TERMINAL: 352,TTY

PLEASE CHANGE YOUR CDC SUPPLIED PASSWORD.

RECOVER /SYSTEM: OLD,CUMS

READY.

-XEDIT

XEDIT 2.1.7

?? M2002

2002 2,0,1.38

? 75

2002 2,0,1.375

?? M2003

2003 3,0,35.69

? 34.745

2003 3,0,34.745

?? M2004

2004 4,0,36.12

? 5

2004 4,0,36.125

?? M2005

2005 5,4.4,36.12

? 5

2005 5,4.4,36.125

?? M2006

2006 6,10.2,36.12

? 5

INPUT AND OUTPUT OF GENSAF PROGRAM
ON COMPACTOR SCHEDULE ANALYSIS

GENSAF PROGRAM A

2006 6,10.2,36.125
?? M2007
2007 7,10.8,36.12
? 5
2007 7,10.8,36.125
?? M2008
2008 8,14.7,36.12
? 5
2008 8,14.7,36.125
?? M2014
2014 14,-1,36.12
? 5
2014 14,-1,36.125
?? Q,,RL
CUMS. REPLACED
CUMS IS A LOCAL FILE
READY.
EXEC,LIB,GENSAP
READY.
RUN

77/12/20. 09.22.25.
PROGRAM GENSAP

SEU 0.119 UNITS.

RUN COMPLETE.
-STRU(F=GENSAP)

STRUPAK ENGINEERING DESIGN LIBRARY
FOR ASSISTANCE CONTACT: CDC APPLICATION SUPPORT (612) 482-2740

ENTER THE NAME OF YOUR DATA FILE.
? OLD,CUMS

DATA FILE OLD,CUM NOT FOUND. TRY AGAIN.

ENTER THE NAME OF YOUR DATA FILE.
? CUMS

OUTPUT WRITTEN TO (CONSOLE OR FILENAME).
? CONSOLE

1-----

12/20/77 09.24.34. PAGE 1

**** GENSAP VER 2.4 ****
STATIC ANALYSIS OF ELASTIC STRUCTURES

CUMS-COMPACTER SUB-MODULE SHEAR

STRUCTURE TYPE = 2
NUMBER OF JOINTS = 14
NUMBER OF JOINTS WITH CONSTRAINTS = 2
NUMBER OF MATERIALS = 1
NUMBER OF MEMBER PROPERTY SETS = 5
NUMBER OF MEMBERS = 14
NUMBER OF MEMBERS WITH RELEASES = 0
NUMBER OF PLATES = 0
NUMBER OF MATRIX ALTERATIONS = 0

JOINT COORDINATES -

JOINT NO.	X-COORD (IN)	Y-COORD (IN)
1	0.0000	0.0000
2	0.0000	1.3750
3	0.0000	34.7450
4	0.0000	36.1250
5	4.4000	36.1250
6	10.2000	36.1250
7	10.8000	36.1250
8	14.7000	36.1250
9	14.7000	0.0000
10	10.8000	0.0000
11	10.2000	0.0000
12	4.4000	0.0000
13	-1.0000	0.0000
14	-1.0000	36.1250

JOINT CONSTRAINTS - (0=UNCONSTRAINED, 1=CONSTRAINED)

JOINT	D-X	D-Y	R-Z
13	1	1	0
14	1	1	0

MATERIAL PROPERTIES -

MATERIAL NUMBER	E (PSI)	PR (IN/IN)	G (PSI)	CTE (IN/DEG)	DENSITY (LB/IN**3)
1	30000000.	.30000000	11500000.	.00000065	.28300000

MEMBER PROPERTY SETS -

PROP MATL SET NO.	AX (IN**2)	ASY (IN**2)	I-ZZ (IN**4)	S-ZZ (IN**3)
----------------------	---------------	----------------	-----------------	-----------------

5-

1	1	1.1000	.9130	.1109	.2017
2	1	.7500	.6230	.0352	.0938
3	1	1.8750	1.5560	.5493	.5859
4	1	3.6250	3.0090	3.9700	2.1901
5	1	.0000	.0000	.0000	.0000

12/20/77 09.24.35. PAGE 2

MEMBER DEFINITIONS -

MEM NO.	JT1	JT2	PROP SET
1	1	2	1
2	2	3	2
3	3	4	1
4	4	5	3
5	5	6	4
6	6	7	3
7	7	8	3
8	9	8	2
9	10	9	3
10	11	10	3
11	12	11	4
12	1	12	3
13	13	1	3
14	14	4	3

NUMBER OF LOADING CASES = 1

LOAD CASE NO. 1 LOAD TYPE 1 MECHANICAL AND INERTIAL LOADS
COMPACTOR LOADING

EXTERNAL FORCES ON JOINTS - (GLOBAL COORDINATE SYSTEM)

JOINT NO.	F-X (LB)	F-Y (LB)	M-Z (IN-LB)
2	-5123.0000	-5123.0000	-2818.0000
3	-5123.0000	5123.0000	2818.0000
5	10246.0000	-1623.0000	-18571.0000
7	-5123.0000	5123.0000	-4803.0000
10	-5123.0000	-5123.0000	4803.0000
12	10246.0000	1623.0000	18571.0000

12/28/77 09.26.10. PAGE 3

BEGINNING TO BUILD THE STIFFNESS MATRIX
SIZE OF STIFFNESS MATRIX = 38
BANDWIDTH = 37
GROUP SIZE = 38
STIFFNESS MATRIX COMPLETE

BEGINNING DECOMPOSITION OF STIFFNESS MATRIX
DECOMPOSITION COMPLETE

BEGINNING SOLUTION FOR DISPLACEMENTS
SOLUTION COMPLETE

12/20/77 09.26.11. PAGE 4

RESULTS FOR LOADING CASE NO. 1

JOINT DISPLACEMENTS - (GLOBAL COORDINATE SYSTEM)

JOINT NO.	D-X (IN)	D-Y (IN)	R-Z (RAD)
1	-.0236355	-.0067808	-.0011174
2	-.0232944	-.0066936	-.0008367
3	.0202716	.0040094	-.0018475
4	.0236355	.0040969	-.0015664
5	.0240363	-.0016117	-.0016716
6	.0237631	-.0097841	-.0015355
7	.0237084	-.0106765	-.0018669
8	.0237084	-.0199166	-.0024986
9	-.0235627	-.0221746	-.0001790
10	-.0235627	-.0209670	-.0008133
11	-.0235081	-.0202513	-.0011450
12	-.0232348	-.0128750	-.0010095
13	0.0000000	0.0000000	-.0020828
14	0.0000000	0.0000000	-.0006011

MEMBER FORCES - (LOCAL COORDINATE SYSTEMS)

MEMBER NO.	JT NO	F-XX (LB)	F-YY (LB)	M-ZZ (IN-LB)
1	1	-2093.5394	-5123.4155	-4201.6413

	2	2093.5394	5123.4155	-2843.0550
2	2	-7216.5394	-.4155	25.0550
	3	7216.5394	.4155	-38.9199
3	3	-2093.5394	5122.5845	2856.9199
	4	2093.5394	-5122.5845	4212.2467
4	4	-5123.2936	-2093.5973	-4212.1888
	5	5123.2936	2093.5973	-4999.6394
5	5	5122.7064	-3716.5973	-13571.3606
	6	-5122.7064	3716.5973	-7984.9038
6	6	5122.7064	-3716.5973	7984.9038
	7	-5122.7064	3716.5973	-10214.8621
7	7	-.2936	1406.4027	5411.8621
	8	.2936	-1406.4027	73.1084
8	9	-1406.4027	-.2936	62.5030
	8	1406.4027	.2936	-73.1084
9	10	.2936	-1406.4027	-5422.4676
	9	-.2936	1406.4027	-62.5030
10	11	5123.2936	3716.5973	-7995.5092
	10	-5123.2936	-3716.5973	10225.4676
11	12	5123.2936	3716.5973	13560.7552
	11	-5123.2936	-3716.5973	7995.5092
12	1	-5122.7064	2093.5973	4201.5834
	12	5122.7064	-2093.5973	5010.2448
13	13	.7091	.0579	-.0000
	1	-.7091	-.0579	.0579
14	14	-.7091	-.0579	-.0000
	4	.7091	.0579	-.0579

} FICTITIOUS

12/20/77 09.27.41. PAGE 5

MEMBER STRESSES - (LOCAL COORDINATE SYSTEMS)

MEMBER NO.	JT NO	AXIAL (PSI)	BEND.-Z (PSI)	COMBINED (PSI)
1	1	1903.2176	-20831.1417	22734.3593
	2	1903.2176	-14095.4637	15998.6813
2	2	9622.0525	267.1112	9889.1637
	3	9622.0525	-414.9247	10036.9773
3	3	1903.2176	14164.2040	16067.4216
	4	1903.2176	20883.7218	22786.9394
4	4	2732.4232	-7189.2623	9921.6855
	5	2732.4232	-8533.2640	11265.6873
5	5	-1413.1604	-6196.6854	-7609.8458
	6	-1413.1604	-3645.9083	-5059.0687
6	6	-2732.1101	13628.4413	-16360.5514
	7	-2732.1101	-17434.4805	-20166.5906
7	7	.1566	9236.8359	9236.9925
	8	.1566	124.7796	124.9362
8	9	1875.2036	666.3428	2541.5463
	8	1875.2036	-779.4068	2654.6104
9	10	-.1566	-9254.9369	-9255.0935
	9	-.1566	-106.6785	-106.8351
10	11	-2732.4232	-13646.5424	-16378.9656
	10	-2732.4232	17452.5816	-20185.0048
11	12	-1413.3224	6191.8429	-7605.1653
	11	-1413.3224	3650.7507	-5064.0731
12	1	2732.1101	7171.1612	9903.2713
	12	2732.1101	8551.3651	11283.4752
13	13	-709065.7931	-.0000	-709065.7931
	1	-709065.7931	57920.6088	-766986.4019

FICTITIOUS

14 14 709065.7705 -.0000 709065.7705 } FICTITIOUS
 4 709065.7705 -57920.6070 766986.3775 }

JOINT EQUILIBRIUM CHECK - (GLOBAL COORDINATE SYSTEM)

JOINT NO.	F-X (LB)	F-Y (LB)	M-Z (IN-LB)
1	.0000	.0000	-.0000
2	-5123.0000	-5123.0000	-2818.0000
3	-5123.0000	5123.0000	2818.0000
4	.0000	.0000	.0000
5	10246.0000	-1623.0000	-18571.0000
6	.0000	.0000	.0000
7	-5123.0000	5123.0000	-4803.0000
8	.0000	.0000	-.0000
9	.0000	.0000	-.0000
10	-5123.0000	-5123.0000	4803.0000
11	-.0000	-.0000	-.0000
12	10246.0000	1623.0000	18571.0000
13	.7091	.0579	-.0000 } FICTITIOUS
14	-.7091	-.0579	-.0000 }

READY.
 BYE

H1886KQ LOG OFF 09.30.27.
 SBU 21.538
 TIO = 11462

>
 COMM. INTERFACE ERROR
 Line Loss - error number 130

FIN2

OLD

RUN

KC,N1886KQ

NET 060042

PLEASE SIGN ON--KC,N1886KQ

77/12/27. 11.09.49.

EASTERN CYBERNET CENTER SN166 NOS

1.0/411.399.0-0

PASSWORD

00000000

TERMINAL: 351,TTY

PLEASE CHANGE YOUR CDC SUPPLIED PASSWORD.

RECOVER /SYSTEM: OLD,GASH

READY.

06.29.07. WARNING

ALL USERS PLS TYPE INFO FOR HOLIDAY HRS

-XEDIT

XEDIT 2.1.7

?? M5006

5006 6,1,1,.83,.0833,.1667

? 2 1.66,.6667,.6667

5006 6,1,2,1.66,.6667,.6667

?? Q,,RL

GASH REPLACED

GASH IS A LOCAL FILE

READY.

EXEC,LIB,GENSAP

READY.

RUN

77/12/27. 11.13.43.

PROGRAM GENSAP

GENSAP PROGRAM B

INPUT AND OUTPUT OF GENSAP PROGRAM
ON GAG AND SHEAR SUBMODULE

CONDITION 1

ENTER THE NAME OF YOUR DATA FILE.
? GASH

OUTPUT WRITTEN TO (CONSOLE OR FILENAME).
? CONSOLE

1-----

12/27/77 11.14.27. PAGE 1

**** GENSAP VER 2.4 ****
STATIC ANALYSIS OF ELASTIC STRUCTURES

GASH-GAG-SHEAR SUB-MODULE

STRUCTURE TYPE = 2
NUMBER OF JOINTS = 21
NUMBER OF JOINTS WITH CONSTRAINTS = 2
NUMBER OF MATERIALS = 1
NUMBER OF MEMBER PROPERTY SETS = 8
NUMBER OF MEMBERS = 21
NUMBER OF MEMBERS WITH RELEASES = 0
NUMBER OF PLATES = 0
NUMBER OF MATRIX ALTERATIONS = 0

JOINT COORDINATES -

JOINT NO.	X-COORD (IN)	Y-COORD (IN)
1	0.0000	0.0000
2	0.0000	1.3800
3	0.0000	1.9100

4	0.0000	34.0400
5	0.0000	34.4400
6	0.0000	36.1300
7	4.8000	36.1300
8	6.9000	36.1300
9	6.9000	37.4400
10	8.0000	36.1300
11	9.0000	36.1300
12	11.0000	36.1300
13	11.0000	34.4400
14	11.0000	34.0400
15	11.0000	1.8100
16	11.0000	1.3800
17	11.0000	0.0000
18	8.5000	0.0000
19	5.5000	0.0000
20	5.5000	-1.1900
21	2.5000	0.0000

JOINT CONSTRAINTS - (0=UNCONSTRAINED, 1=CONSTRAINED)

JOINT	D-X	D-Y	R-Z
9	1	1	0
20	1	1	0

MATERIAL PROPERTIES -

MATERIAL NUMBER	E (PSI)	PR (IN/IN)	G (PSI)	CTE (IN/DEG)	DENSITY (LB/IN**3)
1	30000000.	.30000000	11500000.	.000000065	.283000000

12/27/77 11.14.27. PAGE 2

MEMBER PROPERTY SETS -

PROP SET	MATL NO.	AX (IN**2)	ASY (IN**2)	I-ZZ (IN**4)	S-ZZ (IN**3)
1	1	1.1600	.9630	.1301	.2243
2	1	.7500	.6230	.0352	.0938
3	1	1.8750	1.5560	.5493	.5859
4	1	3.6250	3.0090	3.9700	2.1901
5	1	4.2000	3.4860	6.1740	2.9400
6	1	2.0000	1.6600	.6667	.6667
7	1	3.3800	2.8050	3.2179	1.9041
8	1	6.0000	4.9800	18.0000	6.0000

MEMBER DEFINITIONS -

MEM NO.	JT1	JT2	PROP SET
1	1	2	1
2	2	3	1
3	3	4	2
4	4	5	1
5	5	6	1
6	6	7	3
7	7	8	4
8	8	9	5

9 8 10 4
 10 10 11 4
 11 11 12 3
 12 12 13 6
 13 13 14 6
 14 14 15 2
 15 15 16 6
 16 16 17 6
 17 17 18 3
 18 18 19 7
 19 19 20 8
 20 19 21 3
 21 21 1 3

NUMBER OF LOADING CASES = 1

LOAD CASE NO. 1 LOAD TYPE 1 MECHANICAL AND INERTIAL LOADS

GAG+SHEAR LOADING

EXTERNAL FORCES ON JOINTS - (GLOBAL COORDINATE SYSTEM)

JOINT NO.	F-X (LB)	F-Y (LB)	M-Z (IN-LB)
2	-940.0000	-940.0000	-738.0000
5	-940.0000	940.0000	738.0000
13	1520.0000	1520.0000	-2478.0000

12/27/77 11.16.04. PAGE 3

16 1520.0000 -1520.0000 2478.0000

BEGINNING TO BUILD THE STIFFNESS MATRIX
SIZE OF STIFFNESS MATRIX = 59
BANDWIDTH = 59
GROUP SIZE = 59
STIFFNESS MATRIX COMPLETE

BEGINNING DECOMPOSITION OF STIFFNESS MATRIX
DECOMPOSITION COMPLETE

BEGINNING SOLUTION FOR DISPLACEMENTS
SOLUTION COMPLETE

JOINT DISPLACEMENTS - (GLOBAL COORDINATE SYSTEM)

JOINT NO.	D-X (IN)	D-Y (IN)	R-Z (RAD)
1	.0004053	.0010841	-.0000542
2	.0003179	.0010777	-.0000657
3	.0003447	.0010874	-.0000599
4	-.0015906	.0022046	-.0004991
5	-.0013894	.0022135	-.0005075
6	-.0002020	.0022058	-.0005204
7	-.0002022	.0003758	-.0001869
8	-.0001841	.0000041	-.0001570
9	0.0000000	0.0000000	-.0001542
10	-.0001687	-.0001562	-.0001480
11	-.0001547	-.0002943	-.0001419
12	-.0001005	-.0004968	-.0000955
13	-.0001779	-.0004903	-.0001915
14	-.0002542	-.0004989	-.0001904
15	.0013407	-.0023466	-.0002938
16	.0012142	-.0023558	-.0002951
17	.0006099	-.0023505	-.0003982
18	.0005425	-.0012745	-.0004224
19	.0004976	-.0000026	-.0004077
20	0.0000000	0.0000000	-.0004085
21	.0004473	.0008281	-.0001785

MEMBER FORCES - (LOCAL COORDINATE SYSTEMS)

MEMBER NO.	JT NO	F-XX (LB)	F-YY (LB)	M-ZZ (IN-LB)
1	1	160.0818	-944.1351	-618.9300
	2	-160.0818	944.1351	-683.9764
2	2	-779.9182	-4.1351	-54.0236
	3	779.9182	4.1351	52.2455
3	3	-779.9182	-4.1351	-52.2455

	4	779.9182	4.1351	-81.0287
4	4	-779.9182	-4.1351	81.0287
	5	779.9182	4.1351	-82.6827
5	5	160.0818	935.8649	820.6827
	6	-160.0818	-935.8649	760.9290
6	6	-935.8649	160.0818	-760.9290
	7	935.8649	-160.0818	1529.3215
7	7	-935.8649	160.0818	-1529.3215
	8	935.8649	-160.0818	1365.4932
8	8	390.2209	-587.6860	-769.8686
	9	-390.2209	587.6860	-.0000
9	8	-1523.5509	-230.1391	-1095.6246
	10	1523.5509	230.1391	842.4716
10	10	-1523.5509	-230.1391	-842.4716
	11	1523.5509	230.1391	612.3325
11	11	-1523.5509	-230.1391	-612.3325
	12	1523.5509	230.1391	152.0543
12	12	230.1391	-1523.5509	-152.0543

12/27/77 11.17.33. PAGE 6

	13	-230.1391	1523.5509	-2422.7467
13	13	-1289.8609	-3.5509	-55.2533
	14	1289.8609	3.5509	53.8329
14	14	-1289.8609	-3.5509	-53.8329
	15	1289.8609	3.5509	-60.6119
15	15	-1289.8609	-3.5509	60.6119
	16	1289.8609	3.5509	-62.1387

(10)

16	16	230.1391	1516.4491	2540.1387
	17	-230.1391	-1516.4491	-447.4390
17	17	-1516.4491	230.1391	447.4390
	18	1516.4491	-230.1391	127.9000
18	18	-1516.4491	230.1391	-127.9000
	19	1516.4491	-230.1391	818.3261
19	19	390.2209	572.3140	681.0537
	20	-390.2209	-572.3140	- .0000
20	19	-944.1351	-160.0818	-1499.3798
	21	944.1351	160.0818	1019.1345
21	21	-944.1351	-160.0818	-1019.1345
	1	944.1351	160.0818	618.9300

MEMBER STRESSES - (LOCAL COORDINATE SYSTEMS)

MEMBER NO.	JT NO	AXIAL (PSI)	BEND.-Z (PSI)	COMBINED (PSI)
1	1	-138.0015	-2759.3850	-2897.3865
	2	-138.0015	-3049.3820	-3187.3835
2	2	672.3433	-240.8543	913.1976
	3	672.3433	232.9270	905.2703
3	3	1039.8910	-556.9885	1596.8795
	4	1039.8910	-863.8452	1903.7362
4	4	672.3433	361.2514	1033.5947
	5	672.3433	-368.6256	1040.9689
5	5	-138.0015	3658.8619	-3796.8634
	6	-138.0015	3392.4608	-3530.4623
6	6	499.1279	-1298.7352	1797.8632
	7	499.1279	2610.2091	3109.3370
7	7	258.1696	-698.2884	956.4581
	8	258.1696	851.7845	1109.9541
8	8	-92.9097	-261.8601	-354.7698
	9	-92.9097	- .0000	-92.9097
9	8	420.2899	-500.2624	920.5523
	10	420.2899	384.6727	804.9625

10	10	420.2899	-384.6727	804.9625
	11	420.2899	279.5911	699.8810
11	11	812.5605	-1045.1143	1857.6748
	12	812.5605	259.5225	1072.0030
12	12	-115.0696	-228.0700	-343.1395
	13	-115.0696	-3633.9384	-3749.0079
13	13	644.9304	-82.8758	727.8062
	14	644.9304	80.7453	725.6758
14	14	1719.8145	-573.9118	2293.7263
	15	1719.8145	-646.1819	2365.9964
15	15	644.9304	90.9132	735.8437
	16	644.9304	-93.2035	738.1339
16	16	-115.0696	3810.0176	-3925.0072
	17	-115.0696	-671.1249	-786.1944

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17	17	808.7729	763.6780	1572.4509
	18	808.7729	218.3117	1027.0845
18	18	448.6536	-67.1755	515.8291
	19	448.6536	429.7706	878.4242
19	19	-65.0368	113.5089	-178.5458
	20	-65.0368	-.0000	-65.0368
20	19	503.5387	-2559.1053	3062.6441
	21	503.5387	1739.4342	2242.9729
21	21	503.5387	-1739.4342	2242.9729
	1	503.5387	1056.3749	1559.9136

JOINT EQUILIBRIUM CHECK - (GLOBAL COORDINATE SYSTEM)

JOINT NO.	F-X (LB)	F-Y (LB)	M-Z (IN-LB)
1	-.0000	-.0000	.0000
2	-940.0000	-940.0000	-738.0000
3	.0000	.0000	-.0000
4	.0000	-.0000	.0000
5	-940.0000	940.0000	738.0000
6	-.0000	.0000	-.0000
7	.0000	-.0000	-.0000
8	.0000	.0000	.0000
9	-587.6860	-390.2209	-.0000
10	-.0000	0.0000	-.0000
11	-.0000	.0000	-.0000
12	.0000	.0000	-.0000
13	1520.0000	1520.0000	-2478.0000
14	.0000	-.0000	.0000
15	-.0000	.0000	.0000
16	1520.0000	-1520.0000	2478.0000
17	.0000	-.0000	-.0000
18	.0000	.0000	-.0000
19	-.0000	-.0000	.0000
20	-572.3140	390.2209	-.0000
21	.0000	.0000	-.0000

SBU 29.261 UNTS.

RUN COMPLETE.

READY.
M3002
ILLEGAL COMMAND.
-XEDIT
AEB , 0.264UNTS.

SBU 0.398 UNTS.

SBU 0.398 UNTS.

READY.
BYE

M1886KQ LOG OFF 11.24.14.
SBU 31.251
TIO = 14337

COMM. INTERFACE ERROR
Line Loss - error number 130

LIS

77/12/27. 13.59.48.
PROGRAM GASH

1000 GASH-GAG-SHEAR SUB-MODULE
1001 2,1
1002 21,2,1,8,21,0,0,0,1
1003 1,0,1,1,1,0,0,1,1
2001 1,0,0
2002 2,0,1.38
2003 3,0,1.81
2004 4,0,34.04
2005 5,0,34.44
2006 6,0,36.13
2007 7,4.8,36.13
2008 8,6.9,36.13
2009 9,6.9,37.44
2010 10,8,36.13
2011 11,9,36.13
2012 12,11,36.13
2013 13,11,34.44
2014 14,11,34.04
2015 15,11,1.81
2016 16,11,1.38
2017 17,11,0
2018 18,8.5,0
2019 19,5.5,0
2020 20,5.5,-1.19
2021 21,2.5,0
3001 9,1,1,0
3002 20,1,0,0
4001 1,30E6,.3,11.5E6,6.5E-7,.283
5001 1,1,1.16,.963,.1301,.2243
5002 2,1,.75,.623,.0352,.0938

GENSAP PROGRAM C
INPUT AND OUTPUT OF GENSAP PROGRAM
ON GAG AND SHEAR SUBMODULE
CONDITION II

5003 3,1,1.875,1.556,.5493,.5859
5004 4,1,3.625,3.009,3.97,2.1901
5005 5,1,4.2,3.486,6.174,2.94
5006 6,1,2,1.66,.6667,.6667
5007 7,1,3.38,2.805,3.2179,1.9041
5008 8,1,6,4.98,18,6
6001 1,1,2,1
6002 2,2,3,1
6003 3,3,4,2
6004 4,4,5,1
6005 5,5,6,1
6006 6,6,7,3
6007 7,7,8,4
6008 8,8,9,5
6009 9,8,10,4
6010 10,10,11,4
6011 11,11,12,3
6012 12,12,13,6
6013 13,13,14,6
6014 14,14,15,2
6015 15,15,16,6
6016 16,16,17,6
6017 17,17,18,3
6018 18,18,19,7
6019 19,19,20,8
6020 20,19,21,3
6021 21,21,1,3
9500 ECCENTRIC SHEARLOADING
9501 1,1
10000 1,0,0,0,0,0,0,0,0
11001 10,0,16070,0
READY.

EXEC,LIB,GENSAP
READY.
RUN

77/12/27. 14.01.23.
PROGRAM GENSAP

ENTER THE NAME OF YOUR DATA FILE.
? GASH

OUTPUT WRITTEN TO (CONSOLE OR FILENAME).
? CONSOLE

1-----

12/27/77 14.02.00. PAGE 1

**** GENSAP VER 2.4 ****
STATIC ANALYSIS OF ELASTIC STRUCTURES

GASH-GAG-SHEAR SUB-MODULE

STRUCTURE TYPE = 2
NUMBER OF JOINTS = 21
NUMBER OF JOINTS WITH CONSTRAINTS = 2
NUMBER OF MATERIALS = 1
NUMBER OF MEMBER PROPERTY SETS = 8
NUMBER OF MEMBERS = 21
NUMBER OF MEMBERS WITH RELEASES = 0
NUMBER OF PLATES = 0
NUMBER OF MATRIX ALTERATIONS = 0

JOINT COORDINATES -

JOINT NO.	X-COORD (IN)	Y-COORD (IN)
1	0.0000	0.0000
2	0.0000	1.3800
3	0.0000	1.8100
4	0.0000	34.0400
5	0.0000	34.4400
6	0.0000	36.1300
7	4.8000	36.1300
8	6.9000	36.1300
9	6.9000	37.4400
10	8.0000	36.1300
11	9.0000	36.1300
12	11.0000	36.1300
13	11.0000	34.4400
14	11.0000	34.0400
15	11.0000	1.8100
16	11.0000	1.3800
17	11.0000	0.0000
18	8.5000	0.0000
19	5.5000	0.0000
20	5.5000	-1.1900
21	2.5000	0.0000

JOINT CONSTRAINTS - (0=UNCONSTRAINED, 1=CONSTRAINED)

JOINT	D-X	D-Y	R-Z
9	1	1	0
20	1	0	0

MATERIAL PROPERTIES -

MATERIAL NUMBER	E (PSI)	PR (IN/IN)	G (PSI)	CTE (IN/DEG)	DENSITY (LB/IN**3)
--------------------	------------	---------------	------------	-----------------	-----------------------

1 30000000. .3000000 11500000. .00000065 .28300000

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MEMBER PROPERTY SETS -

PROP SET	MATL NO.	AX (IN**2)	ASY (IN**2)	I-ZZ (IN**4)	S-ZZ (IN**3)
1	1	1.1600	.9630	.1301	.2243
2	1	.7500	.6230	.0352	.0938
3	1	1.8750	1.5560	.5493	.5859
4	1	3.6250	3.0090	3.9700	2.1901
5	1	4.2000	3.4860	6.1740	2.9400
6	1	2.0000	1.6600	.6667	.6667
7	1	3.3800	2.8050	3.2179	1.9041
8	1	6.0000	4.9800	18.0000	6.0000

MEMBER DEFINITIONS -

MEM NO.	JT1	JT2	PROP SET
1	1	2	1
2	2	3	1

3	3	4	2
4	4	5	1
5	5	6	1
6	6	7	3
7	7	8	4
8	8	9	5
9	8	10	4
10	10	11	4
11	11	12	3
12	12	13	6
13	13	14	6
14	14	15	2
15	15	16	6
16	16	17	6
17	17	18	3
18	18	19	7
19	19	20	8
20	19	21	3
21	21	1	3

NUMBER OF LOADING CASES = 1

LOAD CASE NO. 1 LOAD TYPE 1 MECHANICAL AND INERTIAL LOADS

ECCENTRIC SHEARLOADING

EXTERNAL FORCES ON JOINTS - (GLOBAL COORDINATE SYSTEM)

JOINT NO.	F-X (LB)	F-Y (LB)	M-Z (IN-LB)
10	0.0000	16070.0000	0.0000

 12/27/77 14.03.40. PAGE 4

RESULTS FOR LOADING CASE NO. 1

JOINT DISPLACEMENTS - (GLOBAL COORDINATE SYSTEM)

JOINT NO.	D-X (IN)	D-Y (IN)	R-Z (RAD)
1	-.0204210	-.1161073	.0166193
2	-.0424042	-.1161389	.0152967
3	-.0488991	-.1161487	.0149061
4	.0546624	-.1172894	.0140430
5	.0489818	-.1172986	.0144002
6	.0233425	-.1173373	.0160072
7	.0233608	-.0371035	.0176979
8	.0233650	.0001671	.0178487
9	0.0000000	0.0000000	.0178465
10	.0233625	.0203068	.0178633
11	.0233603	.0381197	.0178095
12	.0233517	.0729840	.0171758
13	.0520513	.0729616	.0168193
14	.0587580	.0729563	.0167399
15	-.0501878	.0718156	.0162741
16	-.0431772	.0718098	.0163588
17	-.0204241	.0717915	.0166458
18	-.0204348	.0293716	.0171511
19	-.0204420	-.0222272	.0171865
20	0.0000000	-.0222272	.0171859
21	-.0204305	-.0738363	.0170584

MEMBER FORCES - (LOCAL COORDINATE SYSTEMS)

MEMBER NO.	JT NO	F-XX (LB)	F-YY (LB)	M-ZZ (IN-LB)
1	1	796.3634	215.4033	3889.3830
	2	-796.3634	-215.4033	-3592.1264
2	2	796.3634	215.4033	3592.1264
	3	-796.3634	-215.4033	-3499.5029
3	3	796.3634	215.4033	3499.5029
	4	-796.3634	-215.4033	-3442.9463
4	4	796.3634	215.4033	-3442.9463
	5	-796.3634	-215.4033	3529.1076
5	5	796.3634	215.4033	-3529.1076
	6	-796.3634	-215.4033	3893.1392
6	6	-215.4033	796.3634	-3893.1392
	7	215.4033	-796.3634	7715.6834
7	7	-215.4033	796.3634	-7715.6834
	8	215.4033	-796.3634	9388.0464
8	8	16070.0000	457.5977	599.4530
	9	-16070.0000	-457.5977	.0000
9	8	242.1944	-15273.6366	-9987.4994
	10	-242.1944	15273.6366	-6813.5009
10	10	242.1944	796.3634	6813.5009
	11	-242.1944	-796.3634	-6017.1375
11	11	242.1944	796.3634	6017.1375
	12	-242.1944	-796.3634	-4424.4108
12	12	-796.3634	242.1944	4424.4108

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	13	796.3634	-242.1944	-4015.1023
13	13	-796.3634	242.1944	4015.1023
	14	796.3634	-242.1944	-3918.2245
14	14	-796.3634	242.1944	3918.2245
	15	796.3634	-242.1944	3887.7009
15	15	-796.3634	242.1944	-3887.7009
	16	796.3634	-242.1944	3991.8444
16	16	-796.3634	242.1944	-3991.8444
	17	796.3634	-242.1944	4326.0727
17	17	-242.1944	-796.3634	-4326.0727
	18	242.1944	796.3634	2335.1643
18	18	-242.1944	-796.3634	-2335.1643
	19	242.1944	796.3634	-53.9258
19	19	-.0000	457.5977	544.5413
	20	.0000	-457.5977	.0000
20	19	215.4033	-796.3634	-490.6155
	21	-215.4033	796.3634	-1898.4746
21	21	215.4033	-796.3634	1898.4746
	1	-215.4033	796.3634	-3889.3830

MEMBER STRESSES - (LOCAL COORDINATE SYSTEMS)

MEMBER NO.	JT NO	AXIAL (PSI)	BEND.-Z (PSI)	COMBINED (PSI)
1	1	-686.5201	17340.0935	-18026.6136
	2	-686.5201	-16014.8300	-16701.3502
2	2	-686.5201	16014.8300	-16701.3502
	3	-686.5201	-15601.8856	-16288.4057
3	3	-1061.8178	37308.1337	-38369.9515
	4	-1061.8178	36705.1843	-37767.0021
4	4	-686.5201	-15349.7382	-16036.2584
	5	-686.5201	15733.8726	-16420.3927

MEMBER STRESSES - (LOCAL COORDINATE SYSTEMS)

MEMBER NO.	JT NO	AXIAL (PSI)	BEND.-Z (PSI)	COMBINED (PSI)
1	1	-686.5201	17340.0935	-18026.6136
	2	-686.5201	-16014.8300	-16701.3502
2	2	-686.5201	16014.8300	-16701.3502
	3	-686.5201	-15601.8856	-16288.4057
3	3	-1061.8178	37308.1337	-38369.9515
	4	-1061.8178	36705.1843	-37767.0021
4	4	-686.5201	-15349.7382	-16036.2584
	5	-686.5201	15733.8726	-16420.3927
5	5	-686.5201	-15733.8726	-16420.3927
	6	-686.5201	17356.8401	-18043.3603
6	6	114.9818	-6644.7162	6759.5980
	7	114.9818	13168.9424	13283.8242
7	7	59.4216	-3522.9622	3582.4038
	8	59.4216	4286.5835	4346.0051
8	8	-3826.1905	203.8956	-4030.0861
	9	-3826.1905	.0000	-3826.1905
9	8	-66.8122	-4560.2938	-4627.1060
	10	-66.8122	-3111.0456	-3177.8578
10	10	-66.8122	3111.0456	-3177.8578
	11	-66.8122	-2747.4259	-2814.2382
11	11	-129.1703	10269.9053	-10399.0756
	12	-129.1703	-7551.4777	-7680.6480
12	12	398.1817	6636.2844	7034.4660
	13	398.1817	-6022.3523	6420.5339
13	13	398.1817	6022.3523	6420.5339
	14	398.1817	-5877.0429	6275.2246
14	14	1061.8178	41772.1161	42833.9339
	15	1061.8178	41446.7042	42508.5221
15	15	398.1817	-5831.2597	6229.4414
	16	398.1817	5987.4673	6385.6490

16	16	398.1817	-5987.4673	6385.6490
	17	398.1817	6488.7846	6886.9663

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17	17	129.1703	-7383.6366	7512.8070
	18	129.1703	3985.6022	4114.7725
18	18	71.6551	-1226.3874	1298.0426
	19	71.6551	-28.3209	99.9760
19	19	.0000	90.7569	90.7569
	20	.0000	.0000	.0000
20	19	-114.8818	-837.3707	-952.2525
	21	-114.8818	-3240.2706	-3355.1524
21	21	-114.8818	3240.2706	-3355.1524
	1	-114.8818	-6638.3051	-6753.1869

JOINT EQUILIBRIUM CHECK - (GLOBAL COORDINATE SYSTEM)

JOINT NO.	F-X (LB)	F-Y (LB)	M-Z (IN-LB)
1	.0000	.0000	-.0000
2	.0000	.0000	-.0000
3	-.0000	-.0000	-.0000
4	-.0000	-.0000	-.0000
5	.0000	.0000	.0000
6	-.0000	-.0000	.0000
7	-.0000	.0000	.0000

8	-.0000	.0000	-.0000
9	457.5977	-16070.0000	.0000
10	.0000	16070.0000	.0000
11	.0000	-.0000	.0000
12	.0000	.0000	-.0000
13	.0000	-.0000	0.0000
14	.0000	.0000	.0000
15	.0000	-.0000	-.0000
16	-.0000	.0000	.0000
17	-.0000	.0000	.0000
18	-.0000	0.0000	-.0000
19	.0000	.0000	-.0000
20	-457.5977	-.0000	.0000
21	-.0000	-.0000	-.0000

-END OF FILE-
?

609.

```
LIS
100 READ P,E,E1,L
110 DATA 100000,0,2.75E+7,222
120 FOR N=2 TO 3.5 STEP 0.5
130 D=6
140 A=PI*D↑2/4
150 R=D/4
160 C=D/2
170 B=SQR(N*P/(E1*A))
180 B1=L/(2*R)
190 S=N*P/A*(1+(L/400+E)*C/R↑2/ABS(COS(B*B1)))
200 PRINT N,D,S
210 PRINT
230 NEXT N
240 END
```

RUN		
2	6	21046.4914567
2.5	6	35937.2213352
3	6	77730.7656454
3.5	6	1.170401197E+7

GENSAP PROGRAM D
YIELDING POINT OF MATERIAL REQUIRED
AS A FUNCTION OF FACTORY OF SAFETY

shear

LIS

```
100 READ P,E,E1,L
110 DATA 400000,0.375,2.75E+7,169.85
120 FOR N=2 TO 3.5 STEP 0.5
130 D=8
140 A=PI*D↑2/4
150 R=D/4
160 C=D/2
170 B=SQR(H*P/(E1*A))
180 B1=L/(2*R)
190 S=H*P/A*(1+(L/400+E)*C/R↑2/ABS(COS(B*B1)))
200 PRINT N,D,S
210 PRINT
230 NEXT N
240 END
```

RUN

2	8	40292.5725895
2.5	8	58163.804147
3	8	84615.9669872
3.5	8	130160.283062

compactor

LIS

```
100 READ P,E,E1,L
110 DATA 400000,0,2.75E+7,179.85
120 FOR N=2 TO 3.5 STEP 0.5
130 D=8
140 A=PI*D↑2/4
150 R=D/4
160 C=D/2
170 B=SQR(N*P/(E1*A))
180 B1=L/(2*R)
190 S=N*P/A*(1+(L/400+E)*C/R↑2/ABS(COS(B*B1)))
200 PRINT N,D,S
210 PRINT
230 NEXT N
240 END
```

RUH

2

8

31145.695117

2.5

8

45188.8348375

3

8

67945.6462421

3.5

8

117669.328529

APPENDIX D

LINEAR ROLLER BEARING SYSTEM ANALYSIS

REPORT BY

THE FRANKLIN INSTITUTE RESEARCH LABORATORIES

FOR

ORNL REMOTELY OPERABLE MODULAR SHEAR CONCEPTUAL DESIGN

LINER ROLLER BEARING SYSTEM

Discussions were held between Gulf + Western and ORNL. To establish an acceptable method for providing reciprocating motion of the compactor. GAG and shear tool assemblies under high load, stroke, temperature, dry lubrication and hot-cell atmospheric conditions.

Various methods were discussed and initially investigated such as: sliding contact, rolling contact using ball bearings, and pressurized nitrogen gas.

Following this, it was decided to use the services of Franklin Institute Research Laboratories (FIRL) specialists in the field of liner bearings technique.

Meetings were held between Gulf + Western and FIRL to discuss and define the technical requirements and associated problems leading to a recommendation and selection of an acceptable method for liner motion of the shear tooling, meeting the design criteria.

FIRL investigated two type of rolling methods, ball design and roller design. The results dictated the use of rollers having the higher load carrying capacity.

FIRL also recommended the material to meet the conditions as M50 high speed tool steel, the selection for this material was based on the following:

- . High hardness efficiency
- . High load carrying capability
- . Superior to other materials above 300⁰F
- . The only proven rolling contact bearing material used for high temperature conditions
- . Life factors based on Rockwell hardness of RC 58 and above on 3x and 5x depending on the heat treatment

FIRL selected a computer program (F-C4846) which provides the means for analyzing a system of liner roller bearings, including the ability for changing geometric parameters for the optimization of bearing performance. The theoretical background for this program is outlined in Appendix D pages 1 thru 48.

This program was used by G+W to determine the type, size, orientation, and number of roller bearings required for each of the compactor, gag, and shear moving tool submodules. The basic criteria for these calculations was one year minimum life requirement under conditions previously stated in this section. The lubrication used for the roller bearing assemblies will be a molybdenum disulphide surface coating on the lined bearing rail contact surface with the rollers.

Calculations and analyses are shown in Appendix C.

This program was used also for the analysis of the Wall Enclosure Hydraulic Stem Slide System.

F-C4846

LINEAR ROLLER BEARING SYSTEM ANALYSIS

by

Robert A. Pallini
John H. Rumbarger

December 1977

Prepared for

Gulf and Western
Swarthmore, Pa.

THE FRANKLIN INSTITUTE RESEARCH LABORATORIES
THE BENJAMIN FRANKLIN PARKWAY • PHILADELPHIA, PENNSYLVANIA 19103

COORDINATE SYSTEM

INNER RACE SHOWN IN FIRST QUADRANT $+X, +Y$
 INNER IS MOVING RACE.

OUTER IS FIXED.

Z AXIS ALWAYS AXIS OF MOTION.

TERMINOLOGY

Z_j = TOTAL ROLLERS IN ROW J

n = INDIVIDUAL ROLLER NO.

Φ = FRACTION OFFSET OF MID-ROLLER FROM X_j

B_j = CHORDAL DISTANCE IN ROW J

J = ROW NO.

Cl_j = LOCATION OF N^{th} ROLLER ALONG Z AXIS

L_j = DISTANCE OF SYSTEM ORIGIN TO BRG. ORIGIN

XL_j, YL_j = LOCATION OF ROLLER CENTER IN X, Y PLANE

JHK
CHECKED BY
RAP

11/77
DATE
11/77

RESEARCH LABORATORIES
PHILADELPHIA, PA. 19103

PROJECT
02G-04846-01

TITLE

LINEAR BEARING SYSTEM ANALYSIS

ROLLER LOCATION ALONG Z

EVEN

$Z = 4$

$\Phi = 0$

N	1	2	3	4
C_{ij}/B	-1.5	1.5	1.5	-1.5

+ 1.5
?

ODD

$Z = 5$

$\Phi = 0$

N	1	2	3	4	5
C_{ij}/B	-2	-1	0	+1	-2

$$C_{ij} = \left[n - \frac{Z_j}{2} - 0.5 + \Phi \right] B_j$$

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TITLE LINEAR BEARING SYSTEM ANALYSIS			

CONTACT ANGLES & QUADRANTS

$$\beta_j = +45^\circ$$

$$\beta_j = -45^\circ$$

$$\beta_j = 180 + 45 = +225^\circ$$

$$\beta_j = 180 - 45 = +135^\circ$$

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TITLE

LINEAR BEARING SYSTEM ANALYSIS

EQUATIONS OF EQUILIBRIUM

LOADS AND MOMENTS APPLIED TO ORIGIN

POSITIVE SENSE OF LOADS AND MOMENTS IN POSITIVE SENSE OF COORDINATE SYSTEM.

ROLLER LOADS P_{nj} ARE ALL ACTING ON INNER OR MOVING RACE.

$$F_x - \sum_{j=1}^i \sum_{n=1}^z P_{nj} \cos \beta_j \neq 0 = E1$$

$$F_y - \sum_{j=1}^i \sum_{n=1}^z P_{nj} \sin \beta_j \neq 0 = E2$$

$$M_x + \sum_{j=1}^i \sum_{n=1}^z P_{nj} [C_{nj} + L_j] \sin \beta_j \neq 0 = E3$$

$$M_y - \sum_{j=1}^i \sum_{n=1}^z P_{nj} [C_{nj} + L_j] \cos \beta_j \neq 0 = E4$$

$$M_z + \sum_{j=1}^i \sum_{n=1}^z P_{nj} \cos \beta_j Y_{Lj} - \sum_{j=1}^i \sum_{n=1}^z P_{nj} \sin \beta_j X_{Lj} \neq 0 = E5$$

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TITLE

LINEAR BEARING SYSTEM ANALYSIS

ROLLER LOAD

$$P_{nj} = K_{nj} \delta_{nj}^{10/9}$$

WHERE

$$K_j = (5.21 \times 10^6) L_{eff}^{8/9}$$

 L_{eff} = EFFECTIVE
ROLLER
LENGTH

AND

 δ_{nj} = DEFLECTION OF THE
NTH ROLLER IN THE jTH BEARING

$$\begin{aligned} \delta_{nj} = & X_j \cos \beta_j + Y_j \sin \beta_j - (\alpha X_j \cdot C_{nj}) \sin \beta_j \\ & + (\alpha Y_j \cdot C_{nj}) \cos \beta_j + (\alpha Z_j \cdot X_{Lj}) \sin \beta_j \\ & - (\alpha Z_j \cdot Y_{Lj}) \cos \beta_j + X_j'' \cos \beta_j + Y_j'' \sin \beta_j \end{aligned}$$

WHERE

 X_j'' & Y_j'' ARE INITIAL OFFSETS (SHIM)
IN THE X AND Y DIRECTION
FOR THE jTH BRG.

$$\delta_{nj} \geq 0$$

TITLE

LINEAR BEARING SYSTEM ANALYSIS

SOLUTION PROCEDURE

- 1.) GEOMETRY & APPLIED LOADS ARE INPUT
- 2.) INITIAL DISPLACEMENT GUESSES ARE READ IN $(X, Y, \alpha X, \alpha Y, \alpha Z)$ AT THE SYSTEM ORIGIN.
- 3.) COMPUTE DEFLECTIONS OF j^{th} BRG. IN TERMS OF ORIGIN DEFLECTIONS.
- 4.) COMPUTE δ_{mj} FOR EACH ROLLER
- 5.) COMPUTE STIFFNESS MATRIX OF PARTIAL DERIVATIVES
- 6.) COMPUTE LOADS
- 7.) DO NEWTON-RAPHSON ITERATION UNTIL ERRORS $\epsilon_1 - \epsilon_5$ ARE ≈ 0

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TITLE

LINEAR BEARING SYSTEM ANALYSIS

$$X_j = X + (\alpha Y) L_j$$

$$Y_j = Y - (\alpha X) L_j$$

$$\alpha X_j = \alpha X$$

$$\alpha Y_j = \alpha Y$$

$$\alpha Z_j = \alpha Z$$

DEFLECTION OF THE j^{th}
BEARING IN TERMS OF
DEFLECTIONS AT THE
ORIGIN.

SWITCHING TO NUMERICAL SUBSCRIPTS

$$X = X_1$$

$$Y = X_2$$

$$\alpha X = X_3$$

$$\alpha Y = X_4$$

$$\alpha Z = X_5$$

$$F_X = F_1 = E_1$$

$$F_Y = F_2 = E_2$$

$$M_X = F_3 = E_3$$

$$M_Y = F_4 = E_4$$

$$M_Z = F_5 = E_5$$

FORM a_{ij} $\left(\begin{matrix} i=1,5 \\ j=1,5 \end{matrix} \right)$ STIFFNESS MATRIX FOR
NEWTON-RAPHSON MATRIX
INVERSION SOLUTION

$$a_{ij} = \frac{\partial F_i}{\partial X_j}$$

WHERE ALL DERIVATIVES ARE
WITH RESPECT TO DISPLACEMENT
AT THE ORIGIN

TITLE

LINEAR BEARING SYSTEM ANALYSIS

MAKING SUBSTITUTIONS THE DEFLECTION OF THE n^{th} ROLLER OF THE j^{th} BEARING DUE TO THE DEFLECTIONS AT THE ORIGIN IS

$$\begin{aligned} \delta_{nj} = & (X_1 + X_4 \cdot L_j) \cos \beta_j + (X_2 - X_3 \cdot L_j) \sin \beta_j \\ & - X_3 \cdot c_{nj} \sin \beta_j + X_4 \cdot c_{nj} \cos \beta_j \\ & + X_5 [X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j] \\ & + X_j'' \cos \beta_j + Y_j'' \sin \beta_j \end{aligned}$$

DERIVATIVES $\partial \delta_{nj} / \partial X_i \quad i = 1-5$

$$\partial \delta_{nj} / \partial X_1 = \cos \beta_j$$

$$\partial \delta_{nj} / \partial X_2 = \sin \beta_j$$

$$\partial \delta_{nj} / \partial X_3 = - (L_j + c_{nj}) \sin \beta_j$$

$$\partial \delta_{nj} / \partial X_4 = (L_j + c_{nj}) \cos \beta_j$$

$$\partial \delta_{nj} / \partial X_5 = X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j$$

TITLE

LINEAR BEARING SYSTEM ANALYSIS

$$\frac{\partial \epsilon_1}{\partial x_i} = \frac{\partial}{\partial x_i} \left[F_1 - \sum_{j=1}^z \sum_{n=1}^z P_{nj} \cos \beta_j \right]$$

$$\frac{\partial \epsilon_1}{\partial x_i} = \frac{\partial}{\partial x_i} \left[- \sum_{j=1}^z \sum_{n=1}^z K_j S_{nj}^{10/9} \cos \beta_j \right]$$

$$\frac{\partial \epsilon_1}{\partial x_i} = - \frac{10}{9} \sum_{j=1}^z K_j \sum_{n=1}^z S_{nj}^{1/9} \frac{\partial S_{nj}}{\partial x_i} \cos \beta_j$$

So Now

$$a_{11} = \frac{\partial \epsilon_1}{\partial x_1} = - \frac{10}{9} \sum_{j=1}^z K_j \sum_{n=1}^z S_{nj}^{1/9} \cos^2 \beta_j$$

$$a_{12} = \frac{\partial \epsilon_1}{\partial x_2} = - \frac{10}{9} \sum_{j=1}^z K_j \sum_{n=1}^z S_{nj}^{1/9} \sin \beta_j \cos \beta_j$$

$$a_{13} = \frac{\partial \epsilon_1}{\partial x_3} = + \frac{10}{9} \sum_{j=1}^z K_j \sum_{n=1}^z S_{nj}^{1/9} (L_j + C_{nj}) \sin \beta_j \cos \beta_j$$

$$a_{14} = \frac{\partial \epsilon_1}{\partial x_4} = - \frac{10}{9} \sum_{j=1}^z K_j \sum_{n=1}^z S_{nj}^{1/9} (L_j + C_{nj}) \cos^2 \beta_j$$

$$a_{15} = \frac{\partial \epsilon_1}{\partial x_5} = - \frac{10}{9} \sum_{j=1}^z K_j \sum_{n=1}^z S_{nj}^{1/9} (X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j) \cdot \cos \beta_j$$

LINEAR BEARING SYSTEM ANALYSIS

$$\frac{\partial \mathcal{E}_2}{\partial X_i} = \frac{\partial}{\partial X_i} \left[F_2 - \sum_j \sum_{n=1}^2 P_{nj} \sin \beta_j \right]$$

$$\frac{\partial \mathcal{E}_2}{\partial X_i} = \frac{\partial}{\partial X_i} \left[- \sum_j \sum_{n=1}^2 K_j S_{nj}^{10/9} \sin \beta_j \right]$$

$$\frac{\partial \mathcal{E}_2}{\partial X_i} = - \frac{10}{9} \sum_j K_j \sum_{n=1}^2 S_{nj}^{1/9} \frac{\partial S_{nj}}{\partial X_i} \sin \beta_j$$

So Now

$$a_{21} = \frac{\partial \mathcal{E}_2}{\partial X_1} = - \frac{10}{9} \sum_j K_j \sum_{n=1}^2 S_{nj}^{1/9} \cos \beta_j \sin \beta_j$$

$$a_{22} = \frac{\partial \mathcal{E}_2}{\partial X_2} = - \frac{10}{9} \sum_j K_j \sum_{n=1}^2 S_{nj}^{1/9} \sin^2 \beta_j$$

$$a_{23} = \frac{\partial \mathcal{E}_2}{\partial X_3} = + \frac{10}{9} \sum_j K_j \sum_{n=1}^2 S_{nj}^{1/9} (L_j + C_{L_{nj}}) \sin^2 \beta_j$$

$$a_{24} = \frac{\partial \mathcal{E}_2}{\partial X_4} = - \frac{10}{9} \sum_j K_j \sum_{n=1}^2 S_{nj}^{1/9} (L_j + C_{L_{nj}}) \cos \beta_j \sin \beta_j$$

$$a_{25} = \frac{\partial \mathcal{E}_2}{\partial X_5} = - \frac{10}{9} \sum_j K_j \sum_{n=1}^2 S_{nj}^{1/9} (X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j) \sin \beta_j$$

TITLE

LINEAR BEARING SYSTEM ANALYSIS

$$\begin{aligned}\frac{\partial E_3}{\partial X_i} &= \frac{\partial}{\partial X_i} \left[F_3 + \sum_j \sum_k P_{nj} \sin \beta_j (C_{nj} + L_j) \right] \\ &= \frac{\partial}{\partial X_i} \left[+ \sum_j \sum_k K_j S_{nj}^{10/9} \sin \beta_j (C_{nj} + L_j) \right]\end{aligned}$$

$$\frac{\partial E_3}{\partial X_i} = +10/9 \sum_j K_j \sum_k S_{nj}^{1/9} \left(\frac{\partial S_{nj}}{\partial X_i} \right) (C_{nj} + L_j) \sin \beta_j$$

So Now

$$A_{31} = \frac{\partial E_3}{\partial X_1} = +10/9 \sum_j K_j \sum_k S_{nj}^{1/9} (C_{nj} + L_j) \sin \beta_j \cos \beta_j$$

$$A_{32} = \frac{\partial E_3}{\partial X_2} = 10/9 \sum_j K_j \sum_k S_{nj}^{1/9} (C_{nj} + L_j) \sin^2 \beta_j$$

$$A_{33} = \frac{\partial E_3}{\partial X_3} = -10/9 \sum_j K_j \sum_k S_{nj}^{1/9} (C_{nj} + L_j)^2 \sin^2 \beta_j$$

$$A_{34} = \frac{\partial E_3}{\partial X_4} = 10/9 \sum_j K_j \sum_k S_{nj}^{1/9} (C_{nj} + L_j)^2 \sin \beta_j \cos \beta_j$$

$$\begin{aligned}A_{35} = \frac{\partial E_3}{\partial X_5} &= 10/9 \sum_j K_j \sum_k S_{nj}^{1/9} (C_{nj} + L_j) \sin \beta_j \\ &\quad (X L_j \sin \beta_j - Y L_j \cos \beta_j)\end{aligned}$$

TITLE

LINEAR BEARING SYSTEM ANALYSIS

$$\frac{\partial \mathcal{E}_4}{\partial X_i} = \frac{\partial}{\partial X_i} \left[F_4 - \sum_{j=1}^4 \sum_{n=1}^2 P_{nj} [C_{nj} + L_j] \cos \beta_j \right]$$

$$= \frac{\partial}{\partial X_i} \left[- \sum_{j=1}^4 \sum_{n=1}^2 K_j S_{nj}^{10/9} [L_j + C_{nj}] \cos \beta_j \right]$$

$$\frac{\partial \mathcal{E}_4}{\partial X_i} = -\frac{10}{9} \sum_{j=1}^4 K_j \sum_{n=1}^2 S_{nj}^{1/9} \frac{\partial S_{nj}}{\partial X_i} [L_j + C_{nj}] \cos \beta_j$$

So Now

$$A_{41} = \frac{\partial \mathcal{E}_4}{\partial X_1} = -\frac{10}{9} \sum_{j=1}^4 K_j \sum_{n=1}^2 S_{nj}^{1/9} [L_j + C_{nj}] \cos^2 \beta_j$$

$$A_{42} = \frac{\partial \mathcal{E}_4}{\partial X_2} = -\frac{10}{9} \sum_{j=1}^4 K_j \sum_{n=1}^2 S_{nj}^{1/9} [L_j + C_{nj}] \cos \beta_j \sin \beta_j$$

$$A_{43} = \frac{\partial \mathcal{E}_4}{\partial X_3} = -\frac{10}{9} \sum_{j=1}^4 K_j \sum_{n=1}^2 S_{nj}^{1/9} [L_j + C_{nj}]^2 \cos \beta_j \sin \beta_j$$

$$A_{44} = \frac{\partial \mathcal{E}_4}{\partial X_4} = -\frac{10}{9} \sum_{j=1}^4 K_j \sum_{n=1}^2 S_{nj}^{1/9} [L_j + C_{nj}]^2 \cos^2 \beta_j$$

$$A_{45} = \frac{\partial \mathcal{E}_4}{\partial X_5} = -\frac{10}{9} \sum_{j=1}^4 K_j \sum_{n=1}^2 S_{nj}^{1/9} [L_j + C_{nj}] \cos \beta_j$$

$$\cdot [X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j]$$

TITLE

LINEAR BEARING SYSTEM ANALYSIS

$$\frac{\partial \mathcal{E}_5}{\partial X_i} = \frac{\partial}{\partial X_i} \left[F_5 + \sum_j \sum_l P_{nj} \cos \beta_j Y_{Lj} - \sum_j \sum_l P_{nj} \sin \beta_j X_{Lj} \right]$$

$$= \frac{\partial}{\partial X_i} \left[- \sum_j \sum_l P_{nj} (X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j) \right]$$

$$\frac{\partial \mathcal{E}_5}{\partial X_i} = -\frac{10}{9} \sum_j K_j \sum_l \delta_{nj}^{\frac{1}{9}} \left(\frac{\partial \delta_{nj}}{\partial X_i} \right) [X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j]$$

So Now

$$a_{51} = \frac{\partial \mathcal{E}_5}{\partial X_1} = -\frac{10}{9} \sum_j K_j \sum_l \delta_{nj}^{\frac{1}{9}} [X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j] \cdot \cos \beta_j$$

$$a_{52} = \frac{\partial \mathcal{E}_5}{\partial X_2} = -\frac{10}{9} \sum_j K_j \sum_l \delta_{nj}^{\frac{1}{9}} [X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j] \cdot \sin \beta_j$$

$$a_{53} = \frac{\partial \mathcal{E}_5}{\partial X_3} = +\frac{10}{9} \sum_j K_j \sum_l \delta_{nj}^{\frac{1}{9}} [X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j] \cdot (L_j + Cl_{nj}) \sin \beta_j$$

$$a_{54} = \frac{\partial \mathcal{E}_5}{\partial X_4} = -\frac{10}{9} \sum_j K_j \sum_l \delta_{nj}^{\frac{1}{9}} [X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j] \cdot (L_j + Cl_{nj}) \cos \beta_j$$

$$a_{55} = \frac{\partial \mathcal{E}_5}{\partial X_5} = -\frac{10}{9} \sum_j K_j \sum_l \delta_{nj}^{\frac{1}{9}} [X_{Lj} \sin \beta_j - Y_{Lj} \cos \beta_j]$$

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PROJECT

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TITLE

LINEAR BEARING SYSTEM ANALYSIS

LIFE THEORY (1)

FROM WEIBULL THEORY

$$\log \frac{1}{S} \approx \frac{\tau_0^c N^e V}{z_0^h}$$

WHERE

S = PROBABILITY OF SURVIVAL

τ_0 = SUBSURFACE SHEAR STRESS

$$\tau_0 = \sqrt{\frac{Q \epsilon P}{l_c}}$$

z_0 = DEPTH TO SHEAR

$$z_0 = \sqrt{\frac{Q}{l_c \epsilon P}}$$

ϵP = CURVATURES

l_c = LENGTH

Q = ROLL LOAD

N = MILLIONS OF STRESS REPETITIONS

$$N = M L$$

M = STRESS / OSC.
 L = MILLIONS OSC.
LIFE

V = STRESSED VOLUME

$$V = l_s l_c \quad l_s = \text{STRESSED LENGTH}$$

So

$$\log \frac{1}{S} \approx \frac{\left[\frac{Q \epsilon P}{l_c} \right]^{c/2}}{\left[\frac{Q}{l_c \epsilon P} \right]^{h/2}} M^e L^e l_s l_c$$

(1) RUMBARGER, JONES "DYNAMIC CAPACITY OF OSCILLATING ROLLING ELEMENT BEARINGS"

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TITLE

LINEAR BEARING SYSTEM ANALYSIS

SIMPLIFY AND TRANSPOSE

$$Q L^{2/c-h+1} \sim B^* \left[\Sigma \rho^{\frac{c+h-1}{2}} l_e^{-\frac{c+h+1}{2}} M^c l_s \right]^{-\frac{2}{c-h+1}}$$

$$B^* = \log \frac{1}{5}$$

ASSUME

$$L = 1 \text{ MILLION REV.}$$

ALSO NOW

$$c = 10 \frac{1}{3}$$

$$h = 2 \frac{1}{3}$$

$$e = 9/8$$

SO NOW

$$Q_{LIN} = B^* \Sigma \rho^{-35/27} l_e^{7/9} M^{-1/4} l_s^{-2/9}$$

THIS IS NOW THE FORM OF THE CAPACITY EQUATION
FOR ONE RACE SEGMENT OF A LINEAR BRG.

FOR A ROTATING BRG.:

$$\Sigma \rho = \frac{1}{D(1+C_i \delta)}$$

$$M = \frac{7}{2} [1 - C_i \delta]$$

$$l_s = \pi d_m [1 + C_i \delta]$$

SO THAT

$$Q_c = \left(\frac{B^* 2^{1/4}}{\pi^{1/4}} \right) \frac{(1 + C_i \delta)^{29/27}}{(1 - C_i \delta)^{1/4}} l_e^{7/9} \left(\frac{D}{d_m} \right)^{2/9} D^{29/27} \Sigma^{-1/4}$$

THEN

$$\frac{B^* 2^{1/4}}{\pi^{1/4}} = 49,500 \quad (\text{LUNDBERG CONSTANT})$$

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TITLE

LINEAR BEARING SYSTEM ANALYSIS

OR

$$B^* = 53,682$$

SO FINAL FORM OF EQUATION IS

$$Q_{LIN} = \lambda (53682) \Sigma R^{-\frac{35}{27}} l_c^{\frac{2}{9}} \mu^{-\frac{1}{4}} l_s^{-\frac{2}{9}}$$

BOTH RACES HAVE IDENTICAL CAPACITY

AND $\Sigma R = \frac{2}{D}$ FOR LINEAR AND TAKING
THE STATISTICAL COMBINATION

$$\frac{1}{Q_i^e} = \frac{2}{Q^e}$$

THUS

$$Q_i = \lambda (11,802) D^{\frac{35}{27}} l_c^{\frac{2}{9}} \mu^{-\frac{1}{4}} l_s^{-\frac{2}{9}}$$

STROKE $S \leq 2B$ TO PREVENT OVERLAPPING
OF STRESSED AREAS,

$$\text{SO } l_s = \frac{S}{2}$$

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02G-C4245-01

TITLE

LINEAR BEARING SYSTEM ANALYSIS

THE LIFE L_i OF A SEGMENT IS

$$L_i = \left(\frac{Q_i}{P_i} \right)^4 \text{ MILLIONS INCHES TRAVEL}$$

WHERE P_i = INDIVIDUAL ROLL LOADSSTATISTICALLY COMBINING i SEGMENTSWHERE $M=1$ STRESS REPETITIONS/STROKE

$$\frac{1}{L_{BRG}} = \sum_{i=1}^z \left(\frac{P_i}{Q_i} \right)^{4e}$$

$$\frac{1}{L_{BRG}} = \sum_{i=1}^z \left(\frac{P_i}{\lambda (11802) D^{35/27} l_c^{1/9} l_s^{-2/9}} \right)^{4e}$$

$$\frac{1}{L_{BRG}} = \left[\frac{1}{\lambda (11802) D^{35/27} l_c^{1/9} l_s^{-2/9}} \right]^{4e} \sum_{i=1}^z P_i^{4e} \cdot \left(\frac{z}{e} \right)$$

SIMPLIFYING

$$\frac{1}{L_{BRG}} = \left[\frac{\lambda (11802) D^{35/27} l_c^{1/9}}{z^{1/e} l_s^{2/9}} \right]^4 \frac{1}{\left\{ \frac{1}{z} \sum_{i=1}^z P_i^{4e} \right\}^{1/e}}$$

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TITLE

LINEAR BEARING SYSTEM ANALYSIS

Now

$$L_{BRG} = \left(\frac{C_{LIN}}{P_E} \right)^4 \text{ Millions Inches}$$

WHERE

$$P_E = \left\{ \frac{1}{Z} \sum_{i=1}^Z P_i \right\}^{1/4e}$$

AND

$$C_{LIN} = \frac{\lambda (13,767) D^{35/27} l_e^{7/9}}{Z^{1/4e} S^{2/9}}$$

STRESS THEORY

FOR LINE CONTACT WITH
RECTANGULAR CONTACT

SEMI-WIDTH

$$b = \sqrt{\frac{P_0 (\nu_a + \nu_b)}{\pi L \left(\frac{1}{R_a} + \frac{1}{R_b} \right)}}$$

WHERE

$$\nu_a = \frac{4(1 - \delta_a^2)}{E_a}$$

$$\nu_b = \frac{4(1 - \delta_b^2)}{E_b}$$

WITH

$$\delta_a = \delta_b = \text{POISSON'S RATIO}$$

$$E_a = E_b = \text{YOUNG'S MODULUS}$$

FOR THE LINEAR BEARING SYSTEM

$$\left(\frac{1}{R_a} + \frac{1}{R_b} \right) = \frac{2}{D} + \frac{1}{\infty}$$

so

$$b = \sqrt{\frac{P_0 (\nu_a + \nu_b)}{\pi L \left(\frac{2}{D} \right)}}$$

THE MEAN COMPRESSIVE STRESS IS OBTAINED
BY DIVIDING THE AREA OF THE PRESSURE
RECTANGLE INTO TOTAL LOAD.

$$S_M = \frac{P_0}{2bL}$$

AND NOW FROM JONES SUB-SURFACE SHEAR
STRESS;

$$S_s = .30025 S_{MAX}$$

WHERE $S_{MAX} = \frac{4S_M}{\pi}$

THUS

$$S_s = 0.3823 S_M$$

AND DEPTH TO SHEAR;

$$z = 0.7861 b$$

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PROJECT <i>02G-C4845-01</i>

LISTING

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C      MAIN ROUTINE
C***** LINEAR IS A PROGRAM FOR ANALYSIS OF UP TO 8 LINEAR ROLLER
C      BEARINGS EACH WITH UP TO 50 ELEMENTS, WITH 5 DEGREES OF
C      FREEDOM.
C      DEGREE OF FREEDOM 1 IS ALONG SYSTEM X1 AXIS ( X AXIS ).
C      DEGREE OF FREEDOM 2 IS ALONG SYSTEM X2 AXIS ( Y AXIS ).
C      DEGREE OF FREEDOM 3 IS ABOUT SYSTEM X1 AXIS.
C      DEGREE OF FREEDOM 4 IS ABOUT SYSTEM X2 AXIS.
C      DEGREE OF FREEDOM 5 IS ABOUT SYSTEM Z AXIS.
C      AXIS OF SYSTEM TRAVEL IS Z AXIS.
C*****
C      INPUT MAP FOR PROGRAM LINEAR
C      CARD TYPE 1 (20A4)
C      TITLE = ANY 80 COLUMN HEADING
C      CARD TYPE 2 (8I,E)
C      IDF(I),I=1,5 = 0 IF DEGREE OF FREEDOM NOT APPLICABLE
C                   = 1 IF DEGREE OF FREEDOM IS APPLICABLE
C      NB = NUMBER OF BEARINGS IN SYSTEM
C      KLUMOR = 0 IF ONLY PROBLEM
C              = 1 IF NEW PROBLEM FOLLOWS
C              = 2 IF NEW LOADS FOLLOWS
C      IDIAG = 0 IF NO DIAGNOSTIC PRINTOUT
C             = 1 IF DIAGNOSTIC PRINTOUT
C      STRK = WORKING STROKE OF THE SYSTEM (IN.)
C      CARD TYPE 3 (5E)
C      FO(I),I=1,5 = APPLIED LOAD IN I TH DIRECTION (LB.)
C      CARD TYPE 4 (5E)
C      XGIN(I),I=1,5 = INITIAL DISPLACEMENT GUESS IN I TH DIR. (IN)
C      CARD TYPE 5 (I)
C      NZ(J) = NUMBER OF ROLLERS IN BEARING J

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LINEAR BEARING SYSTEM ANALYSIS

C***** CARD TYPE 6 (6E)

C
C DR(J) = ROLLER DIAMETER (IN.)
C B(J) = CHORDAL SPACING (IN.)
C BETAIN(J) = CONTACT ANGLE (DEG.)
C EFFL(J) = EFFECTIVE LENGTH OF ROLLER (IN.)
C PHI(J) = FRACTION OFFSET OF FIRST ROLLER (IN.)
C SL(J) = LOCATION OF BEARING CENTER (IN.)

C***** CARD TYPE 7 (2E)

C
C XL(J) = X LOCATION OF ROLLER CENTER IN X,Y PLANE (IN.)
C YL(J) = Y LOCATION OF ROLLER CENTER IN X,Y PLANE (IN.)

C***** CARD TYPE 8 (2E)

C
C XSHIM(J) = INITIAL OFFSET IN X DIRECTION (IN.)
C YSHIM(J) = INITIAL OFFSET IN Y DIRECTION (IN.)

C***** CARD TYPES 5 TO 8 TO BE REPEATED NB TIMES

C
C*****

DIMENSION TITLE(20),IDF(5),XIN(8,5),NDEG(5),ADEG(5),ATITLE
1(5),SUM(5),XGIN(5),FO(5),EPS(5),A(5,5),RS(5),BB(5,5),DXO(5)
3,XO(5)

COMMON/ROLL/DR(8),B(8),BETAIN(8),EFFL(8),PHI(8),SL(8),XL(8)
2,YL(8),BETA(8),F1(8),F2(8),F3(8),F4(8),F5(8),AC(8,5,5)
3,J,NZ(8),PJPHI(8,50),DELF(50),CL(8,50)
4,X1(8),X2(8),X3(8),X4(8),X5(8)

COMMON/TIME/BL(8),STRK
COMMON/OFF/XSHIM(8),YSHIM(8)
DOUBLE PRECISION ATITLE,ADEG

C
C OPEN(UNIT=5,DEVICE='DSK',FILE='LINEAR.DAT')

C
C OPEN(UNIT=6,DEVICE='DSK',FILE='LINEAR.LPT')

C
3 READ(5,100)TITLE

READ(5,101)(IDF(I),I=1,5),NB,KLUMOR,IDIAG,STRK

READ(5,102)(FO(I),I=1,5)

READ(5,102)(XGIN(I),I=1,5)

DO 5 J=1,NB

READ(5,103)NZ(J)

READ(5,102)DR(J),B(J),BETAIN(J),EFFL(J),PHI(J),SL(J)

READ(5,102)XL(J),YL(J)

READ(5,102)XSHIM(J),YSHIM(J)

BETA(J)=BETAIN(J)*0.017453

5 CONTINUE

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C
C
C

DETERMINE DEGREES OF FREEDOM PERMITTED

XXTST=0.000001

NI=15

NCT=0

10 IDEG=0

DATA ATITLE/8H ALONG X,8H ALONG Y,8H ABOUT X,8H ABOUT Y,8H ABOUT Z
1/

DO 15 I=1,5

IF(IDF(I).EQ.0)GO TO 15

IDEG=IDEG+1

NDEG(IDEG)=I

ADEG(IDEG)=ATITLE(I)

15 CONTINUE

DO 16 I=1,8

BL(I)=0.0

16 CONTINUE

DO 17 I=1,5

XO(I)=XGIN(I)

17 CONTINUE

C
C
C

COMPUTE INITIAL DISPLACEMENT AND LOADS AT EACH BRG.

20 DO 25 J=1,NB

X1(J)=XO(1)+SL(J)*XO(4)

X2(J)=XO(2)-SL(J)*XO(3)

X3(J)=XO(3)

X4(J)=XO(4)

X5(J)=XO(5)

CALL ROLLD

25 CONTINUE

DO 30 I=1,5

30 SUM(I)=0.0

DO 40 J1=1,NB

SUM(1)=SUM(1)+F1(J1)

SUM(2)=SUM(2)+F2(J1)

SUM(3)=SUM(3)+F3(J1)

SUM(4)=SUM(4)+F4(J1)

SUM(5)=SUM(5)+F5(J1)

40 CONTINUE

DO 50 I=1,5

EPS(I)=(FO(I)+SUM(I))

50 CONTINUE

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TITLE

LINEAR BEARING SYSTEM ANALYSIS

PERFORM MATRIX OPERATIONS.

DO 60 I1=1,5

DO 60 K1=1,5

A(I1,K1)=0.0

60 CONTINUE

DO 65 J=1,NB

DO 65 JJ=1,5

DO 65 JK=1,5

A(JJ,JK)=A(JJ,JK)+AC(J,JJ,JK)

65 CONTINUE

NCT=NCT+1

IF(NCT.EQ.NI)GO TO 201

DO 280 II=1,IDEG

IIDEG=NDEG(II)

RS(II)=EPS(IIDEG)

DO 280 JJ=1,IDEG

JDEG=NDEG(JJ)

280 BR(II,JJ)=A(IIDEG,JDEG)

IF(INDIAG.EQ.1)WRITE(6,99999)BR,A,RS,EPS,FO,X0,SUM

IF(INDIAG.EQ.1)WRITE(6,99997) X1,X2,X3,X4,X5,F1,F2,F3,F4,F5

99999 FORMAT(' BR'/5(5E15.7/),' A'/5(5E15.7/),' RS',5E15.7/

1' EPS',5E15.7/' FO',5E15.7/' X0',5E15.7/' SUM',5E15.7)

99997 FORMAT(' X1',6E15.7/' X2',6E15.7/' X3',6E15.7/' X4',6E15.7/

1' X5,6E15.7/' F1,6E15.7/' F2',6E15.7/' F3',6E15.7/' F4',

26E15.7/' F5',6E15.7)

CALL MATIN(BR,5,IDEG,RS,DXO,ID)

IF(ID.EQ.2)GO TO 1500

C.....TEST FOR CONVERGENCE

IPASS=0

DO 281 I=1,IDEG

KDEG=NDEG(I)

XO(KDEG)=XO(KDEG)-DXO(I)

TEST=ABS(DXO(I))

281 IF(TEST.LT.XXTST)IPASS=IPASS+1

IF(IPASS.EQ.IDEG)GO TO 200

C.....

DO 282 I=1,5

IF(IDF(I).EQ.1)GO TO 282

XO(I)=0.

282 CONTINUE

GO TO 20

201 NI=NI-1

WRITE(6,1000)NI

200 CONTINUE

C

C.....EQUATE NON APPLICABLE XO(I) AND A(I,K) TO 0 FOR EACH PROBLEM

DO 911 I=1,5

IF(IDF(I).EQ.1)GO TO 909

XO(I)=0.

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```

909 DO 910 J=1,5
    IJDF=IDF(I)+IDF(J)
    IF(IJDF.EQ.2)GO TO 910
    A(I,J)=0.
    DO 9099 K=1,NB
9099 AC(K,I,J)=0.
910 CONTINUE
911 CONTINUE

C
C   WRITE INPUT EDIT
C
    WRITE(6,150)
    WRITE(6,151)
    WRITE(6,152)TITLE
    WRITE(6,28)
    DO 7 J=1,NB
        WRITE(6,29)J,EFFL(J)
        WRITE(6,36)NZ(J),DR(J),SL(J)
        WRITE(6,37)B(J),BETAIN(J),PHI(J)
        WRITE(6,38)XL(J),YL(J)
        WRITE(6,380)XSHIM(J),YSHIM(J)
7 CONTINUE
    WRITE(6,1016)STRK,(FO(I),I=1,5)
    WRITE(6,39)
    WRITE(6,1040)(ADEG(I),I=1,IDEG)
    WRITE(6,10000)

C
C   COMPUTE SYSTEM LIFE
C
    DO 70 J=1,NB
        CALL ROLIF
70 CONTINUE
    SUMLIF=0.0
C   CREATE STATISTICAL LIFE
    DO 75 JJ=1,NB
        IF(DL(JJ)-1.0)73,75,73
73 CONTINUE
        SUMLIF=SUMLIF+(BL(JJ))*(-1.125)
75 CONTINUE
        SYLIFE=SUMLIF*(-1.0/1.125)

C
C   WRITE SYSTEM OUTPUT DATA
C
    WRITE(6,1025)
    WRITE(6,1026)SYLIFE,(SUM(I),I=1,5)
    WRITE(6,1027)(XO(I),I=1,5)
    WRITE(6,1028)
    WRITE(6,1029)(A(1,K),K=1,5),(A(2,2))
    WRITE(6,1030)(A(2,K),K=3,5),(A(3,K),K=3,5)
    WRITE(6,10030)(A(4,K),K=4,5),A(5,5)

```

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```

WRITE(6,1031)
WRITE(6,1036)((J,F1(J),F2(J),F3(J),F4(J),F5(J)),J=1,NB)
WRITE(6,1035)
WRITE(6,1032)
WRITE(6,1036)((J,X1(J),X2(J),X3(J),X4(J),X5(J)),J=1,NB)
WRITE(6,1035)
WRITE(6,10322)
WRITE(6,10323)((J,BL(J)),J=1,NB)
  IF(IDIAG.EQ.0) GO TO 77
WRITE(6,1033)
WRITE(6,1037)((J,(AC(J,1,K),K=1,5)),J=1,NB)
WRITE(6,1035)
WRITE(6,1037)((J,(AC(J,2,K),K=2,5),AC(J,3,3)),J=1,NB)
WRITE(6,1035)
WRITE(6,1037)((J,(AC(J,3,K),K=4,5),(AC(J,4,K),K=4,5),
2AC(J,5,5)),J=1,NB)
77  CONTINUE

```

```

C
C  COMPUTE CONTACT STRESSES AND WRITE BEARING OUTPUT.
C

```

```

DO 80 J=1,NB
CALL ROSTRO
80  CONTINUE
  IF(KLUMOR.EQ.1) GO TO 3
  IF(KLUMOR.EQ.0) GO TO 85
  READ(5,100)TITLE
  READ(5,102)(FO(I),I=1,5)
  NCT=0
  GO TO 10
85  STOP
100  FORMAT(20A4)
101  FORMAT(8I,E)
102  FORMAT(6E)
103  FORMAT(I)
1000 FORMAT(1X,' 15 ITERATIONS NO CONVERGENCE'//)
10000 FORMAT(1H1)
150  FORMAT(1H1)
151  FORMAT(20X,40HROLLING ELEMENT BEARING ANALYSIS PROGRAM/
122X,36H5 DEGREES OF FREEDOM(FX,FY,MX,MY,MZ)//)
152  FORMAT(20A4//)
28  FORMAT(4X,42H*** INPUT DATA FOR INDIVIDUAL BEARINGS ***/)
29  FORMAT(4X,12HBEARING NO. ,I4, 9X,22HBEARING TYPE -ROLL ,
12X,11HROLL LENGTH,1PE12.4)
36  FORMAT(4X,12HNO.ELEMENTS ,I4, 9X,11HELEMENT DIA,1PE12.4,
112H LOCATION ,1PE12.4)
37  FORMAT(4X,12HCHORD SPACE ,1PE12.4,12H CONTACT ANG,1PE12.4,
212H PHI DIST. ,1PE12.4)
38  FORMAT(4X,12HX OFFSET ,1PE12.4,12H Y OFFSET ,1PE12.4)
380 FORMAT(4X,12HX-SHIM ,1PE12.4,12H Y-SHIM ,1PE12.4//)
39  FORMAT(//1X,'INNER RACE IS MOVING'//)

```


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LINEAR BEARING SYSTEM ANALYSIS

```

1016 FORMAT(/30H INPUT DATA FOR BEARING SYSTEM // 20X,44HEXT
2ERNAL FORCES AND MOMENTS APPLIED TO SHAFT /80H (IN)
3      ALONG X      ALONG Y      ABOUT X      ABOUT Y      A
4ABOUT Z      /      (STROKE)      F1
5      F2      F3      F4      F5 //
61P6E12.4)
1040 FORMAT(53H PROBLEM IS POSED IN FOLLOWING DEGREES OF FR
1EEDOM / 1X,5(A8,1H,))
1025 FORMAT(31H OUTPUT DATA FOR BEARING SYSTEM,/)
1026 FORMAT(60H INCHES TRAVEL      SYSTEM REACTIONS ON SHAFT AT OR
1IGIN/
2' (B-10)      ALONG X      ALONG Y      ABOUT X      ABOUT
3 Y      ABOUT Z //1P6E12.4//)
1027 FORMAT(21X,41HDISPLACEMENTS OF REFERENCE LINE AT ORIGIN
1 /14X,'ALONG X      ALONG Y      ABOUT X      ABOUT Y      A
2BOUT Z //12X,1P5E12.4 //)
1028 FORMAT(21X,43HNON-LINEAR SPRING RATES OF SYSTEM AT ORIGIN / )
1029 FORMAT(2X,6HDFX/DX,6X,6HDFX/DY,6X,8HDFX/DALX,4X,8HDFX/DALY,4X,
18HDFX/DALZ,4X,6HDFY/DY/1P6E12.4//)
1030 FORMAT(2X,8HDFY/DALX,4X,8HDFY/DALY,4X,8HDFY/DALZ,4X,8HDMX/DALX,
24X,8HDMX/DALY,4X,8HDMX/DALZ/1P6E12.4//)
10030 FORMAT(2X,8HDMY/DALY,4X,8HDMY/DALZ,4X,8HDMZ/DALZ/1P3E12.4//)
1031 FORMAT(3X,7HBEARING,17X,30HREACTIONS OF BEARINGS ON SHAFT,/5X,
13HNO.,6X,7HALONG X,5X,7HALONG Y,5X,7HABOUT X,5X,7HABOUT Y,5X,
37HABOUT Z/)
1032 FORMAT(3X,7HBEARING,9X,46HRELATIVE SHAFT DISPLACEMENTS AT BEARING
1 CENTER,/5X,3HNO.,6X,7HALONG X,5X,7HALONG Y,5X,7HABOUT X,5X,
27HABOUT Y,5X,7HABOUT Z,/)
10322 FORMAT(3X,7HBEARING,4X,'BEARING B-10 LIVES'/5X,3HNO./)
10323 FORMAT(I7,5X,1P6E12.4)
1033 FORMAT(3X,7HBEARING,3X,56HPARTIAL DERIVATIVES OF BEARING REACTION
1S WITH RESPECT TO/
25X,3HNO.,10X,30HDISPLACEMENTS AT SYSTEM ORIGIN/)
1037 FORMAT(I7,5X1P5E12.4)
1035 FORMAT(/)
1036 FORMAT(I7,5X,1P5E12.4)
1500 WRITE(6,1039) NCT
1039 FORMAT(1X,'MATRIX SINGULAR ITERATION',I5)
STOP
END

```

SUBROUTINE ROLLD

```

C THIS SUBROUTINE COMPUTES LOADS AND MOMENTS AND MATRIX COEFF-
C ICIENTS FOR FIVE DEGREES OF FREEDOM FOR LINEAR CYLINDRICAL
C ROLLER BEARINGS

```

COMMON/OFF/XSHIM(8),YSHIM(8)

COMMON/ROLL/DR(8),R(8),RETAIN(8),EFFL(8),PHI(8),SL(8),XL(8)

2,YL(8),BETA(8),F1(8),F2(8),F3(8),F4(8),F5(8),AC(8,5,5)

3,J,NZ(8),PJPHI(8,50),DELP(50),CL(8,50)

4,X1(8),X2(8),X3(8),X4(8),X5(8)

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7.0

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TITLE

LINEAR BEARING SYSTEM ANALYSIS

INITIALIZE VARIABLES

F1(J)=0.0

F2(J)=0.0

F3(J)=0.0

F4(J)=0.0

F5(J)=0.0

A11=0.0

A12=0.0

A13=0.0

A14=0.0

A15=0.0

A22=0.0

A23=0.0

A24=0.0

A25=0.0

A33=0.0

A34=0.0

A35=0.0

A44=0.0

A45=0.0

A55=0.0

SET CONSTANTS

NR=NZ(J)

RK=5210000.0*EFFL(J)**(8./9.)

CONK=10./9.

CON1=1./9.

SN=SIN(BETA(J))

CN=COS(BETA(J))

RN=FLOAT(NZ(J))

CALCULATE ROLLER LOCATIONS

DO 10 N=1,NR

CL(J,N)=(FLOAT(N)-(RN/2.)-0.5+PHI(J))*B(J)

CONTINUE

CALCULATE FORCES

DO 20 N=1,NR

DELF(N)=(X1(J)*CN)

1

+(X2(J)*SN)

2

-(X3(J)*CL(J,N)*SN)

3

+(X4(J)*CL(J,N)*CN)

4

+X5(J)*(XL(J)*SN-YL(J)*CN)

5

+XSHIM(J)*CN+YSHIM(J)*SN

IF(DELF(N).LT.0.0) DELF(N)=0.0

PJPHI(J,N)=RK*DELF(N)**CONK

F1(J)=F1(J)-PJPHI(J,N)*CN

F2(J)=F2(J)-PJPHI(J,N)*SN

F3(J)=F3(J)+PJPHI(J,N)*(CL(J,N)+SL(J))*SN

F4(J)=F4(J)-PJPHI(J,N)*(CL(J,N)+SL(J))*CN

F5(J)=F5(J)+PJPHI(J,N)*CN*YL(J)-PJPHI(J,N)*SN*XL(J)

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```

CON2=CL(J,N)+SL(J)
CON3=XL(J)*SN-YL(J)*CN
SN2=SN**2.0
CN2=CN**2.0
CON22=CON2**2.0
CON32=CON3**2.0
A11=A11+DELCON*CN2
A12=A12+DELCON*CN*SN
A13=A13+DELCON*CON2*CN*SN
A14=A14+DELCON*CON2*CN2
A15=A15+DELCON*CON3*CN
A22=A22+DELCON*SN2
A23=A23+DELCON*CON2*SN2
A24=A24+DELCON*CON2*CN*SN
A25=A25+DELCON*CON3*SN
A33=A33+DELCON*CON22*SN2
A34=A34+DELCON*CON22*CN*SN
A35=A35+DELCON*CON2*CON3*SN
A44=A44+DELCON*CON22*CN2
A45=A45+DELCON*CON2*CON3*CN
A55=A55+DELCON*CON32
CONTINUE

```

20
C
C
C

FORM COEFFICIENTS A(J,I,K)

```

CON4=RK*CONK
AC(J,1,1)=-CON4*A11
AC(J,1,2)=-CON4*A12
AC(J,1,3)=+CON4*A13
AC(J,1,4)=-CON4*A14
AC(J,1,5)=-CON4*A15
AC(J,2,2)=-CON4*A22
AC(J,2,3)=+CON4*A23
AC(J,2,4)=-CON4*A24
AC(J,2,5)=-CON4*A25
AC(J,3,3)=-CON4*A33
AC(J,3,4)=+CON4*A34
AC(J,3,5)=+CON4*A35
AC(J,4,4)=-CON4*A44
AC(J,4,5)=-CON4*A45
AC(J,5,5)=-CON4*A55

```

C
C
C

CREATE SYMMETRICAL MATRIX

```

NN=2
DO 101 KJ=1,4
DO 100 KK=NN,5
AC(J,KK,KJ)=AC(J,KJ,KK)
NN=NN+1
RETURN
END

```

100
101

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PROJECT

02G-C4246-01

TITLE

LINEAR BEARING SYSTEM ANALYSIS

SUBROUTINE MATIN(Z,NSIZE,JSIZE,H,C,IO)

THIS SUBROUTINE INVERTS MATRICES AND PROVIDES SOLUTIONS
 DIMENSION Z(NSIZE,NSIZE),INDEX(20,3),H(1),C(1)
 EQUIVALENCE (IROW,JROW), (ICOLUMN,JCOLUMN), (AMAX, T, SWAP)

INITIALIZATION

N=JSIZE

DO 20 J=1,N

20 INDEX(J,3) = 0

DO 55 I=1,N

SEARCH FOR PIVOT ELEMENT

AMAX=0.0

DO 105 J=1,N

IF(INDEX(J,3)-1)81,105,81

81 DO 100 K=1,N

IF(INDEX(K,3)-1) 80, 100, 15

80 ZJK=Z(J,K)

IF(AMAX-ABS(ZJK))90,100,100

90 IROW=J

ICOLUMN=K

AMAX = ABS(ZJK)

100 CONTINUE

105 CONTINUE

INDEX(ICOLUMN,3) = INDEX(ICOLUMN,3) +1

INDEX(I,1)=IROW

INDEX(I,2)=ICOLUMN

INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL

IF(IROW-ICOLUMN)91,31 ,91

91 DO 29 L=1,N

SWAP=Z(IROW,L)

Z(IROW,L)=Z(ICOLUMN,L)

29 Z(ICOLUMN,L)=SWAP

DIVIDE PIVOT ROW BY PIVOT ELEMENT

31 PIVOT =Z(ICOLUMN,ICOLUMN)

Z(ICOLUMN,ICOLUMN)=1.0

DO 35 L=1,N

35 Z(ICOLUMN,L)=Z(ICOLUMN,L)/PIVOT

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LINEAR BEARING SYSTEM ANALYSIS

```
C      REDUCE NON-PIVOT ROWS
C
      DO 55 L=1,N
      IF(L1-ICOLUM)92,55 ,92
92     T=Z(L1,ICOLUM)
      Z(L1,ICOLUM)=0.0
      DO 45 L=1,N
45     Z(L1,L)=Z(L1,L)-Z(ICOLUM,L)*T
55     CONTINUE

C      INTERCHANGE COLUMNS
C
      DO 71 I=1,N
      L=N+1-I
      IF(INDEX(L,1)-INDEX(L,2))94,71 ,94
94     JROW=INDEX(L,1)
      JCOLUM=INDEX(L,2)
      DO 70 K=1,N
      SWAP=Z(K,JROW)
      Z(K,JROW)=Z(K,JCOLUM)
      Z(K,JCOLUM)=SWAP
70     CONTINUE
71     CONTINUE
      DO 73 K = 1,N
      IF(INDEX(K,3)-1) 15,72 , 15
72     CONTINUE
73     CONTINUE
      ID =1
      DO 40 I=1,N
      C(I)=0.0
      DO 40 J=1,N
40     C(I)=C(I)+Z(I,J)*H(J)
      GO TO 74
15     ID =2
74     RETURN
```

```
C      LAST CARD OF PROGRAM
C
C
```

END

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TITLE

LINEAR BEARING SYSTEM ANALYSIS

SUBROUTINE ROLIF

THIS ROUTINE COMPUTES LIFE VALUES

COMMON/ROLL/DR(8),B(8),BETAIN(8),EFFL(8),PHI(8),SL(8),XL(8)
2,YL(8),BETA(8),F1(8),F2(8),F3(8),F4(8),F5(8),AC(8,5,5)
3,J,NZ(8),PJPHI(8,50),DELF(50),CL(8,50)
COMMON/TIME/BL(8),STRK

SET CONSTANTS

EXP1=35./27.
EXP2=7./9.
EXP3=2./9.
EXP4=4.5
BSTAR=13767.0
PLAM=0.54

COMPUTE CAPACITY OF J TH BEARING

TOP=PLAM*BSTAR*(DR(J)**EXP1)*(EFFL(J)**EXP2)
BOT=(NZ(J)**EXP3)*(STRK**EXP3)
QC=TOP/BOT

COMPUTE EQUIVALENT LOAD

SUMLD=0.0
DO 10 N=1,NZ(J)
SUMLD=SUMLD+PJPHI(J,N)**EXP4
10 CONTINUE
IF(SUMLD.EQ.0.0) GO TO 20
EQLD=(SUMLD/NZ(J))**EXP3
GO TO 30
20 EQLD=0.005*QC
30 CONTINUE

COMPUTE LIFE IN INCHES TRAVEL

BLMI=(QC/EQLD)**4.0
BL(J)=BLMI*1000000.0
RETURN
END
SUBROUTINE ROSTRO

THIS ROUTINE COMPUTES STRESSES AND WRITES OUTPUT

COMMON/ROLL/DR(8),B(8),BETAIN(8),EFFL(8),PHI(8),SL(8),XL(8)
2,YL(8),BETA(8),F1(8),F2(8),F3(8),F4(8),F5(8),AC(8,5,5)
3,J,NZ(8),PJPHI(8,50),DELF(50),CL(8,50)
DIMENSION RIN(50),SM(50),T45(50),Z45(50)

CHECKED BY

DATE

RAD

12/77

PROJECT

026-C4846-01

TITLE

LINEAR BEARING SYSTEM ANALYSIS

C1=1.2931E-07

RA=DR(J)/2.0

C5=3.141592654*EFFL(J)

CD1=C5*(1.0/RA)

CIN=(2.0*C1)/CD1

N1=NZ(J)

DO 20 N=1,N1

BIN(N)=0.0

SM(N)=0.0

T45(N)=0.0

Z45(N)=0.0

20 CONTINUE

DO 30 N=1,N1

IF(PJPHI(J,N).EQ.0.0) GO TO 30

BIN(N)=(PJPHI(J,N)*CIN)**0.5

SM(N)=(PJPHI(J,N)/(2.0*BIN(N)*EFFL(J)))

Z45(N)=0.7861*BIN(N)

T45(N)=0.3823*SM(N)

30 CONTINUE

NERO=0

DO 40 N=1,N1

IF(PJPHI(J,N))40,40,35

35 NERO=1

40 CONTINUE

WRITE(6,100)

WRITE(6,101) J

IF(NERO.EQ.0) GO TO 90

WRITE(6,102)

WRITE(6,104)((N,CL(J,N),PJPHI(J,N),BIN(N),SM(N),

1 T45(N),Z45(N)),N=1,N1)

90 CONTINUE

IF(NERO.EQ.0) WRITE(6,311) J

100 FORMAT(1H1)

101 FORMAT(1X,29H OUTPUT DATA FOR BEARING NO. ,I2,4X,

1 14HROLLER BEARING//)

102 FORMAT(1X,'ROLLER',3X,'LOCATION',3X,'ROLL LOAD',3X,

1 'SEMI-WIDTH',3X,'HTZ STRESS',2X,'SHEAR STRESS',3X,'DEPTH',

2 3X,'NO.',6X,'(IN)',7X,'(LBS)',8X,'(IN)',6X,'MEAN (PSI)',

3 3X,'MAX (PSI)',5X,'(IN)')/)

104 FORMAT(I5,4X,E10.4,1X,E10.4,2X,E10.4,3X,E10.4,3X,E10.4,2X,E10.4)

311 FORMAT(///3X,'ROLLER BEARING NO.',I3,2X,'NOT LOADED')

RETURN

END

DESIGN GUIDELINES

ROW 1

ROW 2

2 ANGULAR CONTACT
ROLLER BEARINGS

SUPERIMPOSED

- 1 LINEAR BEARING ASSEMBLY IS VIEWED AS
- 2 BEARING ROWS, WITH ALTERNATING CONTACT ANGLES, SUPERIMPOSED.

TITLE

LINEAR BEARING SYSTEM ANALYSIS

TAKING AN ARBITRARY CASE
AND B IS CHORDAL SPACING OF ONE ROW;

END OF
STROKE

MID-STROKE

START OF
STROKE

ROLLER DIAMETER = D

ROLLER EFFECTIVE LENGTH = $l_e = D - .707A - R_c$

WHERE A = RACE SEPARATION

R_c = ROLLER CORNER RADIUS

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026-C4846-01

TITLE

LINEAR BEARING SYSTEM ANALYSIS

FROM LIFE THEORY,

$$S \leq 2B$$

FROM LAYOUT

$$R_L = (Z-1)B + S/2 + 2[E_s]$$

WHERE

 R_L = LENGTH OF FIXED RACE Z = NUMBER OF ROLLERS IN ROW E_s = END SPACEEND SPACE MUST BE $\geq D/2$ + CAGE END + SEAL PLATE

SO THAT

$$Z = \frac{(R_L - S/2 - 2E_s)}{B} + 1$$

KHP 12/11
CHECKED BY DATE

RESEARCH LABORATORIES
PHILADELPHIA, PA. 19103

PROJECT
026-6484-01

TITLE

LINEAR BEARING SYSTEM ANALYSIS

SAMPLE PROBLEM

COMPACTOR TOOL

G & W DRAWING SK-E-3381

KAP 12/77
CHECKED BY DATE

RESEARCH LABORATORIES
PHILADELPHIA, PA. 19103

50
PROJECT
020-C4246-01

TITLE

LINEAR BEARING SYSTEM ANALYSIS

$D = 1.50"$ ALL ROWS

$S = 7"$ SO LET $B = 3.75"$

$l_{eff} = 1.0"$ $E_s = 1.75"$

THUS $Z = 6$ ODD ROWS

$Z = 5$ EVEN ROWS

INPUT

Row	Input Data
00100	GULF AND WESTERN LINEAR BEARINGS ** COMPACTOR **
00200	0 0 0 1 0 8 0 0 2.0
00300	0.0 0.0 0.0 -3200000.0 0.0
00400	0.0 0.0 0.0 -0.001 0.0
00500	6
00600	1.5 3.75 45.0 1.0 0.0 0.0
00700	5.25 9.0
00800	0.0 0.0
00900	5
01000	1.5 3.75 135.0 1.0 0.0 0.0
01100	5.25 9.0
01200	0.0 0.0
01300	6
01400	1.5 3.75 225.0 1.0 0.0 0.0
01500	5.25 -9.0
01600	0.0 0.0
01700	5
01800	1.5 3.75 -45.0 1.0 0.0 0.0
01900	5.25 -9.0
02000	0.0 0.0
02100	6
02200	1.5 3.75 45.0 1.0 0.0 0.0
02300	-5.25 9.0
02400	0.0 0.0
02500	5
02600	1.5 3.75 135.0 1.0 0.0 0.0
02700	-5.25 9.0
02800	0.0 0.0
02900	6
03000	1.5 3.75 225.0 1.0 0.0 0.0
03100	-5.25 -9.0
03200	0.0 0.0
03300	5
03400	1.5 3.75 -45.0 1.0 0.0 0.0
03500	-5.25 -9.0
03600	0.0 0.0

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TITLE LINEAR BEARING SYSTEM ANALYSIS			

OUTPUT

ROLLING ELEMENT BEARING ANALYSIS PROGRAM 5 DEGREES OF FREEDOM(FX,FY,MX,MY,MZ)

GULF AND WESTERN LINEAR BEARINGS ** COMPACTOR **

*** INPUT DATA FOR INDIVIDUAL BEARINGS ***

BEARING NO.	1	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO.ELEMENTS	6	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	4.5000E+01	PHI DIST.	0.0000E+00
X OFFSET	5.2500E+00	Y OFFSET	9.0000E+00		
X-SHIM	0.0000E+00	Y-SHIM	0.0000E+00		

BEARING NO.	2	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO.ELEMENTS	5	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	1.3500E+02	PHI DIST.	0.0000E+00
X OFFSET	5.2500E+00	Y OFFSET	9.0000E+00		
X-SHIM	0.0000E+00	Y-SHIM	0.0000E+00		

BEARING NO.	3	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO.ELEMENTS	6	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	2.2500E+02	PHI DIST.	0.0000E+00
X OFFSET	5.2500E+00	Y OFFSET	-9.0000E+00		
X-SHIM	0.0000E+00	Y-SHIM	0.0000E+00		

BEARING NO.	4	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO.ELEMENTS	5	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	-4.5000E+01	PHI DIST.	0.0000E+00
X OFFSET	5.2500E+00	Y OFFSET	-9.0000E+00		
X-SHIM	0.0000E+00	Y-SHIM	0.0000E+00		

BEARING NO.	5	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO.ELEMENTS	6	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	4.5000E+01	PHI DIST.	0.0000E+00
X OFFSET	-5.2500E+00	Y OFFSET	9.0000E+00		
X-SHIM	0.0000E+00	Y-SHIM	0.0000E+00		

RAD 12/77 CHECKED BY <i>Y</i> DATE		THE FRANKLIN INSTITUTE RESEARCH LABORATORIES PHILADELPHIA, PA. 19103	PROJECT 026-C4246-01
TITLE LINEAR BEARING SYSTEM ANALYSIS			

BEARING NO.	6	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO. ELEMENTS	5	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	1.3500E+02	PHI DIST.	0.0000E+00
X OFFSET	-5.2500E+00	Y OFFSET	9.0000E+00		
X-SHIM	0.0000E+00	Y-SHIM	0.0000E+00		

BEARING NO.	7	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO. ELEMENTS	6	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	2.2500E+02	PHI DIST.	0.0000E+00
X OFFSET	-5.2500E+00	Y OFFSET	-9.0000E+00		
X-SHIM	0.0000E+00	Y-SHIM	0.0000E+00		

BEARING NO.	8	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO. ELEMENTS	5	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	-4.5000E+01	PHI DIST.	0.0000E+00
X OFFSET	-5.2500E+00	Y OFFSET	-9.0000E+00		
X-SHIM	0.0000E+00	Y-SHIM	0.0000E+00		

INPUT DATA FOR BEARING SYSTEM

EXTERNAL FORCES AND MOMENTS APPLIED TO SHAFT					
(IN)	ALONG X	ALONG Y	ABOUT X	ABOUT Y	ABOUT Z
(STROKE)	F1	F2	F3	F4	F5
2.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-3.2000E+06	0.0000E+00

INNER RACE IS MOVING

PROBLEM IS POSED IN FOLLOWING DEGREES OF FREEDOM
ABOUT Y,

OUTPUT DATA FOR BEARING SYSTEM

INCHES TRAVEL		SYSTEM REACTIONS ON SHAFT AT ORIGIN			
(B-10)	ALONG X	ALONG Y	ABOUT X	ABOUT Y	ABOUT Z
2.8703E+02	5.2598E+00	1.3423E+00	-9.0332E+05	3.2003E+06	8.4980E+05

DISPLACEMENTS OF REFERENCE LINE AT ORIGIN				
ALONG X	ALONG Y	ABOUT X	ABOUT Y	ABOUT Z
0.0000E+00	0.0000E+00	0.0000E+00	-2.5646E-03	0.0000E+00

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TITLE LINEAR BEARING SYSTEM ANALYSIS		

NON-LINEAR SPRING RATES OF SYSTEM AT ORIGIN

DFX/DX	DFX/DY	DFX/DALX	DFX/DALY	DFX/DALZ	DFY/DY
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
DFY/DALX	DFY/DALY	DFY/DALZ	DMX/DALX	DMX/DALY	DMX/DALZ
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
DMY/DALY	DMY/DALZ	DMZ/DALZ			
-1.3864E+09	0.0000E+00	0.0000E+00			

BEARING NO.	REACTIONS OF BEARINGS ON SHAFT				
	ALONG X	ALONG Y	ABOUT X	ABOUT Y	ABOUT Z
1	-6.9076E+04	-6.9075E+04	-5.1293E+05	5.1295E+05	2.5905E+05
2	4.5472E+04	-4.5476E+04	2.8710E+05	2.8708E+05	-6.4799E+05
3	6.9084E+04	6.9075E+04	-5.1294E+05	5.1300E+05	9.8440E+05
4	-4.5477E+04	4.5476E+04	2.8710E+05	2.8711E+05	-1.7055E+05
5	-6.9076E+04	-6.9075E+04	-5.1293E+05	5.1295E+05	9.8433E+05
6	4.5472E+04	-4.5476E+04	2.8710E+05	2.8708E+05	-1.7050E+05
7	6.9084E+04	6.9075E+04	-5.1294E+05	5.1300E+05	2.5911E+05
8	-4.5477E+04	4.5476E+04	2.8710E+05	2.8711E+05	-6.4804E+05

BEARING NO.	RELATIVE SHAFT DISPLACEMENTS AT BEARING CENTER				
	ALONG X	ALONG Y	ABOUT X	ABOUT Y	ABOUT Z
1	0.0000E+00	0.0000E+00	0.0000E+00	-2.5649E-03	0.0000E+00
2	0.0000E+00	0.0000E+00	0.0000E+00	-2.5649E-03	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00	-2.5649E-03	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00	-2.5649E-03	0.0000E+00
5	0.0000E+00	0.0000E+00	0.0000E+00	-2.5649E-03	0.0000E+00
6	0.0000E+00	0.0000E+00	0.0000E+00	-2.5649E-03	0.0000E+00
7	0.0000E+00	0.0000E+00	0.0000E+00	-2.5649E-03	0.0000E+00
8	0.0000E+00	0.0000E+00	0.0000E+00	-2.5649E-03	0.0000E+00

BEARING NO.	BEARING B-10 LIVES
1	1.2542E+03
2	3.5183E+03
3	1.2539E+03
4	3.5175E+03
5	1.2542E+03
6	3.5183E+03
7	1.2539E+03
8	3.5175E+03

<div style="text-align: center; font-size: 1.2em; font-weight: bold;">RAD 12/77</div> <div style="display: flex; justify-content: space-between; font-size: 0.8em;"> CHECKED BY DATE </div>	<div style="font-weight: bold;">THE FRANKLIN INSTITUTE</div> <div style="font-weight: bold;">RESEARCH LABORATORIES</div> <div style="font-size: 0.8em;">PHILADELPHIA, PA. 19103</div>	<div style="font-size: 1.5em; font-weight: bold;">4-2</div> <div style="font-size: 0.8em;">PROJECT</div> <div style="font-size: 1.2em; font-weight: bold;">026-C4246-01</div>
<div style="display: flex; justify-content: space-between;"> TITLE LINEAR BEARING SYSTEM ANALYSIS </div>		

OUTPUT DATA FOR BEARING NO. 1 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.9375E+01	.5633E+05	.5897E-01	.4776E+06	.1826E+06	.4636E-0
2	-.5625E+01	.3193E+05	.4440E-01	.3596E+06	.1375E+06	.3491E-0
3	-.1875E+01	.9422E+04	.2412E-01	.1953E+06	.7467E+05	.1896E-0
4	.1875E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+0
5	.5625E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+0
6	.9375E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+0

OUTPUT DATA FOR BEARING NO. 2 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.7500E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+0
2	-.3750E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+0
3	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+0
4	.3750E+01	.2035E+05	.3545E-01	.2871E+06	.1097E+06	.2786E-0
5	.7500E+01	.4396E+05	.5210E-01	.4219E+06	.1613E+06	.4095E-0

OUTPUT DATA FOR BEARING NO. 3 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.9375E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+0
2	-.5625E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+0
3	-.1875E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+0
4	.1875E+01	.9422E+04	.2412E-01	.1953E+06	.7467E+05	.1896E-0
5	.5625E+01	.3194E+05	.4440E-01	.3596E+06	.1375E+06	.3491E-0
6	.9375E+01	.5634E+05	.5898E-01	.4776E+06	.1826E+06	.4636E-0

OUTPUT DATA FOR BEARING NO. 4 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.7500E+01	.4396E+05	.5210E-01	.4219E+06	.1613E+06	.4095E-01
2	-.3750E+01	.2035E+05	.3545E-01	.2871E+06	.1097E+06	.2787E-01
3	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
4	.3750E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
5	.7500E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00

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TITLE LINEAR BEARING SYSTEM ANALYSIS		

OUTPUT DATA FOR BEARING NO. 5 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.9375E+01	.5633E+05	.5897E-01	.4776E+06	.1826E+06	.4636E-01
2	-.5625E+01	.3193E+05	.4440E-01	.3596E+06	.1375E+06	.3491E-01
3	-.1875E+01	.9422E+04	.2412E-01	.1953E+06	.7467E+05	.1896E-01
4	.1875E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
5	.5625E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
6	.9375E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00

OUTPUT DATA FOR BEARING NO. 6 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.7500E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
2	-.3750E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
3	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
4	.3750E+01	.2035E+05	.3545E-01	.2871E+06	.1097E+06	.2786E-01
5	.7500E+01	.4396E+05	.5210E-01	.4219E+06	.1613E+06	.4095E-01

OUTPUT DATA FOR BEARING NO. 7 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.9375E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
2	-.5625E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
3	-.1875E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
4	.1875E+01	.9422E+04	.2412E-01	.1953E+06	.7467E+05	.1896E-01
5	.5625E+01	.3194E+05	.4440E-01	.3596E+06	.1375E+06	.3491E-01
6	.9375E+01	.5634E+05	.5898E-01	.4776E+06	.1826E+06	.4636E-01

OUTPUT DATA FOR BEARING NO. 8 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.7500E+01	.4396E+05	.5210E-01	.4219E+06	.1613E+06	.4095E-01
2	-.3750E+01	.2035E+05	.3545E-01	.2871E+06	.1097E+06	.2787E-01
3	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
4	.3750E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
5	.7500E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00

KAP 12/77
CHECKED BY DATE

THE FRANKLIN INSTITUTE
RESEARCH LABORATORIES
PHILADELPHIA, PA. 19103

44
PROJECT
026-C4846-01

TITLE

LINEAR BEARING SYSTEM ANALYSIS

SAMPLE PROBLEM: SHEAR SYSTEM

G&W DRAWING

SK-E-3399

DR = 1.5 $L_{eff} = 1.0$
B = 3.75 Z = 6 ODD
Z = 5 EVEN

X-SHIM = .020

Y-SHIM = -.020

RAP 12/77 CHECKED BY <u>1</u> DATE <u> </u>		THE FRANKLIN INSTITUTE RESEARCH LABORATORIES PHILADELPHIA, PA. 19103	45 PROJECT 028-C4846-01
TITLE <u>LINEAR BEARING SYSTEM ANALYSIS</u>			

INPUT

00100	GULF AND WESTERN	SHEAR SLIDE SYSTEM	WITH SHIMS
00200	0 0 0 1 0 4 0 0	2.0	
00300	0.0 0.0 0.0	2924000.0	0.0
00400	0.0 0.0 0.0	0.001	0.0
00500	6		
00600	1.5 3.75 45.0	1.0 0.0 0.0	
00700	0.0 11.25		
00800	0.020 -0.020		
00900	5		
01000	1.5 3.75 135.0	1.0 0.0 0.0	
01100	0.0 11.25		
01200	0.20 -0.020		
01300	6		
01400	1.5 3.75 225.0	1.0 0.0 0.0	
01500	0.0 -11.25		
01600	0.020 0.0		
01700	5		
01800	1.5 3.75 -45.0	1.0 0.0 0.0	
01900	0.0 -11.25		
02000	0.020 0.0		

OUTPUT

ROLLING ELEMENT BEARING ANALYSIS PROGRAM
5 DEGREES OF FREEDOM(FX,FY,MX,MY,MZ)

GULF AND WESTERN SHEAR SLIDE SYSTEM WITH SHIMS

*** INPUT DATA FOR INDIVIDUAL BEARINGS ***

BEARING NO.	1	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO.ELEMENTS	6	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	4.5000E+01	PHI DIST.	0.0000E+00
X OFFSET	0.0000E+00	Y OFFSET	1.1250E+01		
X-SHIM	2.0000E-02	Y-SHIM	-2.0000E-02		

BEARING NO.	2	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO.ELEMENTS	5	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	1.3500E+02	PHI DIST.	0.0000E+00
X OFFSET	0.0000E+00	Y OFFSET	1.1250E+01		
X-SHIM	2.0000E-01	Y-SHIM	-2.0000E-02		

RAP 12/77 CHECKED BY DATE		THE FRANKLIN INSTITUTE RESEARCH LABORATORIES PHILADELPHIA, PA. 19103	410 PROJECT 026-C4846-01
TITLE LINEAR BEARING SYSTEM ANALYSIS			

BEARING NO.	3	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO. ELEMENTS	6	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	2.2500E+02	PHI DIST.	0.0000E+00
X OFFSET	0.0000E+00	Y OFFSET	-1.1250E+01		
X-SHIM	2.0000E-02	Y-SHIM	0.0000E+00		

BEARING NO.	4	BEARING TYPE	-ROLL	ROLL LENGTH	1.0000E+00
NO. ELEMENTS	5	ELEMENT DIA	1.5000E+00	LOCATION	0.0000E+00
CHORD SPACE	3.7500E+00	CONTACT ANG	-4.5000E+01	PHI DIST.	0.0000E+00
X OFFSET	0.0000E+00	Y OFFSET	-1.1250E+01		
X-SHIM	2.0000E-02	Y-SHIM	0.0000E+00		

INPUT DATA FOR BEARING SYSTEM

EXTERNAL FORCES AND MOMENTS APPLIED TO SHAFT					
(IN)	ALONG X	ALONG Y	ABOUT X	ABOUT Y	ABOUT Z
(STROKE)	F1	F2	F3	F4	F5
2.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.9240E+06	0.0000E+00

INNER RACE IS MOVING

PROBLEM IS POSED IN FOLLOWING DEGREES OF FREEDOM
ABOUT Y,

1
OUTPUT DATA FOR BEARING SYSTEM

INCHES TRAVEL	SYSTEM REACTIONS ON SHAFT AT ORIGIN				
(B-10)	ALONG X	ALONG Y	ABOUT X	ABOUT Y	ABOUT Z
1.3430E+01	-3.0785E+05	1.2609E+05	6.9264E+05	-2.9240E+06	1.8406E+05

DISPLACEMENTS OF REFERENCE LINE AT ORIGIN				
ALONG X	ALONG Y	ABOUT X	ABOUT Y	ABOUT Z
0.0000E+00	0.0000E+00	0.0000E+00	5.5269E-03	0.0000E+00

NON-LINEAR SPRING RATES OF SYSTEM AT ORIGIN

DFX/DX	DFX/DY	DFX/DALX	DFX/DALY	DFX/DALZ	DFY/DY
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
DFY/DALX	DFY/DALY	DFY/DALZ	DMX/DALX	DMX/DALY	DMX/DALZ
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

RAP 12/77 CHECKED BY _____ DATE _____		THE FRANKLIN INSTITUTE RESEARCH LABORATORIES PHILADELPHIA, PA. 19103	47 PROJECT 026-C424-01
TITLE LINEAR BEARING SYSTEM ANALYSIS			

DMY/DALY	DMY/DALZ	DMZ/DALZ
-6.0471E+08	0.0000E+00	0.0000E+00

BEARING NO.	REACTIONS OF BEARINGS ON SHAFT				
	ALONG X	ALONG Y	ABOUT X	ABOUT Y	ABOUT Z
1	-1.6211E+05	-1.6210E+05	1.2037E+06	-1.2038E+06	1.8237E+06
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	7.1232E+04	7.1223E+04	6.0451E+05	-6.0459E+05	8.0136E+05
4	-2.1698E+05	2.1697E+05	-1.1156E+06	-1.1156E+06	-2.4410E+06

BEARING NO.	RELATIVE SHAFT DISPLACEMENTS AT BEARING CENTER				
	ALONG X	ALONG Y	ABOUT X	ABOUT Y	ABOUT Z
1	0.0000E+00	0.0000E+00	0.0000E+00	5.5269E-03	0.0000E+00
2	0.0000E+00	0.0000E+00	0.0000E+00	5.5269E-03	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00	5.5269E-03	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00	5.5269E-03	0.0000E+00

BEARING NO.	BEARING B-10 LIVES
1	4.1352E+01
2	1.6000E+15
3	3.8450E+02
4	1.8561E+01

1
OUTPUT DATA FOR BEARING NO. 1 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.9375E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
2	-.5625E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
3	-.1875E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
4	.1875E+01	.2211E+05	.3695E-01	.2992E+06	.1144E+06	.2904E-01
5	.5625E+01	.7494E+05	.6802E-01	.5509E+06	.2106E+06	.5347E-01
6	.9375E+01	.1322E+06	.9034E-01	.7316E+06	.2797E+06	.7102E-01

1
OUTPUT DATA FOR BEARING NO. 2 ROLLER BEARING

KMP 12/11	
CHECKED BY/	DATE

RESEARCH LABORATORIES
PHILADELPHIA, PA. 19103

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PROJECT
026-C4846-01

TITLE	LINEAR BEARING SYSTEM ANALYSIS
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ROLLER BEARING NO. 2 NOT LOADED

1

OUTPUT DATA FOR BEARING NO. 3 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.9375E+01	.7689E+05	.6890E-01	.5580E+06	.2133E+06	.5416E-
2	-.5625E+01	.2384E+05	.3836E-01	.3107E+06	.1188E+06	.3016E-
3	-.1875E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+
4	.1875E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+
5	.5625E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+
6	.9375E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+

1

OUTPUT DATA FOR BEARING NO. 4 ROLLER BEARING

ROLLER NO.	LOCATION (IN)	ROLL LOAD (LBS)	SEMI-WIDTH (IN)	HTZ STRESS MEAN (PSI)	SHEAR STRESS MAX (PSI)	DEPTH (IN)
1	-.7500E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+
2	-.3750E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+
3	.0000E+00	.4591E+05	.5324E-01	.4311E+06	.1648E+06	.4185E-
4	.3750E+01	.1012E+06	.7903E-01	.6400E+06	.2447E+06	.6213E-
5	.7500E+01	.1598E+06	.9932E-01	.8044E+06	.3075E+06	.7908E-