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BDX-613-522

EVALUATION OF FOAM MIXING
MACHINES

PDO 6984144, Final Report

R. F. Hetzler, Project Leader

Published November, 1971

**Kansas City
Division**

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Project Leader:
R. F. Hetzler
Department 834

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A prime contractor for the Atomic Energy Commission
Contract Number AT(29-1)-613 USAEC

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ABSTRACT

The evaluation of most of the urethane foam mixing machines used at Bendix Kansas City is discussed. The primary purpose of the evaluation was to prove the ability of these machines to meet the required ± 1 percent repeatability on material flow rates and $\pm 1/2$ °F stability on all components. Investigations to solve machine difficulties, such as head freeze-up and time required for repeated calibration, are also outlined.

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SUMMARY

The primary objective of this project was to establish the capabilities of urethane foam mixing machines as they were installed at Bendix. The procedure was to operate the machines over the range required for production operations, and to determine the ability of each machine to meet the required precision. When the ± 1 percent repeatability of flow rate or the $\pm 1/2^\circ\text{F}$ stability of material temperatures was not met, repairs were specified and re-evaluations were run. As a result of this work, all machines which have been used for production parts have been shown to meet these requirements.

One of the problems was mixing head freeze-up. To prevent this from occurring, two attempts were made to exclude air and moisture from the head of the Admiral 300-lb/min foam machine. Neither attempt was entirely successful, but a modification of the evaluated air-draulic valve actuator provided a solution.

A more promising technique was found which reduces machine downtime caused by head freezing and makes head repair easier and more convenient. This is a head which has external valving.

The evaluation of a positive displacement flow meter was directed toward the possibility of using automatic controllers to allow a preset ratio and dispense rate. The meter appeared to have the necessary accuracy, but is still unusable for the intended purpose. The problems encountered appear to be characteristic of the urethane resin system in this type of meter. The meter is not considered satisfactory for ratio/rate controller applications, and its practicality for other urethane applications is doubtful.

No additional work on this project is planned at this time.

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DISCUSSION

SCOPE AND PURPOSE

This project was undertaken to evaluate and to improve the reliability of the machines used to produce rigid urethane foams. When work was started many new foam machines were being purchased, and it was necessary to evaluate these machines to prove their ability to meet quality standards. When machines were no longer being ordered, efforts were directed toward upgrading those machines which were in use.

PRIOR WORK

No previous work of this type has been performed at Bendix Kansas City.

ACTIVITY

Machine Requirements

One of the primary requirements for the production of high quality urethane foam is to maintain a specific ratio between the components. If the foam is machine-mixed, this ratio is set during calibration. The system must then remain sufficiently stable to maintain the correct ratio until the next calibration which usually takes place 24 hours later. It was a primary function of this project to assure that all foam machines used for production were capable of meeting this requirement.

A foam machine used to mix urethane foam has a system like that outlined in Figure 1 for each component within the machine. It is normally a closed system with a component reservoir and equipment to pump, heat, cool, and dispense the component. The reservoir is blanketed with dry nitrogen. This excludes air and moisture and also maintains a positive head on the suction side of the pump. Material is pumped from the reservoir by a rotary pump driven by a variable speed motor. Because of the high viscosity of the components, the rotary pump is essentially positive displacement.

The material is passed through a heat exchanger in the temperature control system, which maintains the material at constant temperature. The material then flows to the head valve, a three-way valve on the mixing head which normally allows material to return to the reservoir. During dispense cycles, this valve diverts the component into the mixing chamber. In all machines at least two of these systems operate simultaneously and their flow rates are maintained in direct proportion to each other.

Figure 1. Flow Diagram of Foam Mixing Machine

During machine calibration, the valve in the return line is restricted to yield a back pressure equal to that produced by the mixing chamber during the dispense cycle. Also, the pump speed is adjusted to deliver a desired flow rate, as measured by weighing the material dispensed over a known time interval. Once these values are set, a flow rate and a ratio are established.

After the ratio has been established, it must be maintained. To maintain flow rates, both the density and viscosity of the components must be controlled. This is accomplished by controlling the temperature. The required control precision is $\pm 1/2$ °F from a set point.

With the temperature control established, the capability of the machine to maintain ± 1 percent of the flow rate for each component must be demonstrated. The machine is calibrated; then test shots are taken and weighed at various times during the calibration period. This procedure is repeated at three set temperatures over the desired range of flow rates and for each component system before the machine is used for production. Any system not meeting the requirements is modified as necessary.

Head Modifications

The largest of the urethane foam machines at Bendix is the Admiral (BKC 33398). This is a single system, two-component machine capable of dispensing 300 lb/min of mixed foam. Because of the high capacity, each component enters the mixing chamber through three orifices. This results in six three-way valves which are all actuated by a single air cylinder.

There are two problems associated with this design. First, it is difficult to maintain the necessary alignment to assure that all valves fully close. If one valve seat is set higher than the others, leaks occur, and material crystallizes and freezes the head shut. The second problem involves the bores in which the valve spools slide. There are six spools on a 3-1/2-inch-diameter circle, all actuated by the same air cylinder. If a single spool sticks, this can cause misalignment which also prevents the valves from functioning smoothly.

To solve these problems, a cover was made for the head which maintained the ring of orifices under a dry nitrogen blanket during downtimes. This excluded oxygen and moisture and prevented the leaked components from crystallizing. However, the cover did not entirely solve the problem of head freeze-up.

A recommendation was made by the machine manufacturer to convert the air cylinder to an air-draulic actuator for the head valves. By putting a hydraulic accumulator, filled with a liquid, into the air line which opens the valves, air is excluded from the bores in which the valve spools must slide. Figure 2 is a cutaway view of the Admiral head, showing one of the six valve spools connected to the annular piston which moves the spools. Adjacent to that view is the schematic of the air-draulic actuator that was evaluated. This design

Figure 2. Cutaway View of Admiral Head With Air-Hydraulic Valve Actuator

prevents crystallization within the bores and also lubricates and cleans the resin components from the walls.

There was limited success in the evaluations which were run. The air pressure available to operate the head was marginally sufficient prior to the modification. With the additional resistance of moving the accumulator piston, air pressure was frequently insufficient to actuate the valves. There appeared to be no further freezing as had been previously experienced, but there was an excessive buildup of friction due to increased sliding surfaces and also insufficient air pressure (80 psi) available.

A separate air compressor is recommended to deliver the 120-psi air for which the existing head was designed. An air-draulic actuator with a 4- to 6-inch-diameter piston, rather than the 2-inch piston evaluated, could then be added. This would greatly reduce the pressure loss in the accumulator. A low-viscosity plasticizer, such as dimethyl phthalate (DMP), is recommended as the actuator fluid.

New Mixing Head Design

The most complex of the urethane foam machines at Bendix is the Gabriel-Williams (Special Order Bendix). This is a three-system, two-component foam machine. It may be considered as three machines on a single frame with a single mixing head. The original head is shown on this machine in Figure 3. This was an extremely congested design with 12 material lines, 12 air lines, and 6 thermocouple connections on the circumference of a relatively small mixing head.

The primary problem of those associated with this head was that when one component valve was inoperative, the entire machine was down for repair. Because of the complexity, repair was also slower and less satisfactory than desired. A frequent problem occurred when one valve was leaking, because possible contamination prevented the use of the other systems.

A new head was designed for this machine (Figure 4) in which the plumbing was less complex than that previously required (Figure 3). The basic principle was to utilize a separate valve assembly for each component. There are six such assemblies on the machine, but only two are connected to the mixing head at any given time. Figure 5 shows the new head with the mixing chamber. Valve assemblies not in use are stored on a rack. The ability to activate one component at a time was maintained with greater convenience and versatility. All capabilities which existed on the original machine are available, yet only one third of the lines are connected to the head at any given time.

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Figure 3. Multi-System Foam Machine (Original Special Order Bendix)

Figure 4. Multi-System Foam Machine (Present Special Order Berdix)

Figure 5. Close-Up of Foam Mixing Head 6984144-700

It has been demonstrated that the new mixing head design offers a significant advantage for machines with more than two material reservoirs. The new design simplifies the head, reduces machine downtime, and allows rapid replacement of entire valve assemblies. In addition, it is possible to calibrate one system while another is set up.

Flow Meter Evaluation

During machine calibration each component is dispensed separately over a measured time interval and the weight dispensed is recorded. Five successive weights must fall within 1 percent of the desired value to assure calibration, which requires approximately 1 manhour for each day a machine is used. In addition, the material dispensed is not reused for production parts. This material cost becomes especially significant for large, high-capacity machines. A system which could conserve on calibration material, while maintaining the high accuracy of ratio and flow rate control, would result in significant savings in time and money.

Commercially available positive displacement meters were investigated for this purpose. If precise metering of all components were possible, direct digital control of ratio, flow rate, and total quantity dispensed should be possible. The frequently used turbine flow meters were not considered to have the required accuracy, and the precise piston metering pumps cause an undesirable pulsation in the flow rate.

Of the meters evaluated, the one which showed the greatest promise was a Japanese development, involving two intermeshing oval gears driven by the fluid force. The manufacturer, Brooks Instrument Division of Emerson Electric Company, did not claim that the meter had previously been used for urethane resins but knew of no reason why it would not deliver a smooth, precisely-metered flow. The meter purchased was stainless steel, manufactured to operate up to 300 psi with 20,000 centipoise resin from 0.11 to 1.2 gallons per minute (gpm). The output was a digital signal of 35,000 counts/gallon (about 10 pulses/gram).

A test platform was constructed for the evaluation of this meter. It was basically a single component machine, complete with material reservoir, variable-speed pump drive, and a recirculate/dispense valve. The meter to be evaluated was put into the line with pressure gages on each side.

During the initial operation of the equipment, a pressure pulsation was encountered. Initial evaluation was directed toward determining the cause and magnitude of the pulsation. No source of pulsation was found in the pump, and the system operated smoothly when the flow meter was bypassed. A

signal was generated by the meter, but its frequency (indicated flow rate) varied greatly while the pump speed remained constant.

Evaluation of the meter design showed the output to be a "characterized" disc, driven by the metering elements. This disc had 360 marks, spaced non-uniformly to maintain the count rate directly proportional to the flow rate. The marks are in turn counted by a photo-electric sensor which is connected to a digital counter.

On the basis of this principle, the system was adjusted to deliver 360 counts per integration. This condition appeared to be stable. To prove this principle, the system was set to deliver 3600 counts per 10 seconds; then the counter was switched to 1-second integration. The count remained stable at 360 despite the rapid fluctuation shown on the pressure gages. This experiment was tried at 180 and 90 counts, but stability was not obtained.

The pulsation apparently was caused by the meter, and its pattern was repeated every time the metering element cycled. To visualize what was happening within this period, high speed photography was used. Movies were taken of the readout, then viewed frame by frame to analyze the fluctuation in flow rate.

Using a single characteristic cycle of the metering element, and plotting the percent deviation from nominal flow within the cycle versus time, a complex curve as shown in Figure 6 was obtained. Three such cycles were plotted, and the same pattern appeared. The most significant fact is that the deviation from uniform flow is approximately 25 percent when a very short time integration is used (about 20 milliseconds when the cycle time is 1 second).

On the basis of the large pressure fluctuation, which is both caused by and responded to by the meter, this type of meter is not considered satisfactory for the desired application of ratio/rate controller. All indications are that the total quantity indicated is accurate. These large pressure fluctuations are not experienced with oils, according to the manufacturer, and there appears to be nothing impeding the free rotation of the meter elements. Since the resins used for this evaluation are non-lubricating, viscoelastic liquids, the pulsation is probably exaggerated by viscoelastic flow resistance at the intermeshing gear teeth.

Since the meter was considered precise as a totalizer, one further evaluation was undertaken. The pump was set at a low speed (41 rpm) to deliver about 0.22 gpm. Without varying the pump speed, the back pressure was increased in steps, and the indicated flow rate was recorded over a long time interval (2 to 3 minutes). The apparent decrease in flow rate with increasing back pressure is illustrated in Figure 7. The slope of the curve indicates a linear decrease in flow of 0.27 percent for each 10-psi increase in pressure. There was no apparent decrease in pump speed; therefore, this error is essentially pump slippage. This is considered a very

Figure 6. Flow Rate Through Meter

Figure 7. Effect of Pressure on Flow With Constant Pump Speed

small error, and it further justifies the previous assumption that rotary pumps, as used on foam machines, are essentially positive displacement.

ACCOMPLISHMENTS

All machines used at Bendix Kansas City to produce urethane foam products have been evaluated and are known to maintain the required stability of temperature and component flow rates. Methods have been demonstrated to reduce problems with head freezing on both high capacity and multi-system machines. The externally valved head discussed offers a particular advantage for these complex machines.

The present calibration technique is expensive and time-consuming, but no satisfactory alternative appears to be available at this time. Direct digital control of ratio and flow rate does not appear feasible without a method for precise metering of urethane resins with a non-pulsating flow.

FUTURE WORK

At present, no additional work on this project is planned.