JANUARY 1973

MATT-952

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DIAGNOSTIC AND
OTHER DEVICES

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RECEIVED BY TIC FEB 13 1973

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Pneumatic Operated Diagnostic
and Other Devices

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ABSTRACT

In the study of plasmas in the FM-1 Machine at PPL it has become increasingly desirable to make diagnostic measurements with a minimum of disturbance to the plasma, especially since the plasma confinement time has been improved. The probe must be small, and must be inserted and withdrawn quickly, or must be timed precisely with respect to overall time of the experiment being conducted. Pneumatic actuated mechanisms are being used frequently as a means to this end. The latest designs of pneumatic probe mechanisms and other devices and systems employed in the FM-1 at PPL are described as well as their operation and operating characteristics.

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I. INTRODUCTION

The standard design of a probe positioning mechanism used at PPL is designated IIIP. The evolution of the IIIP mechanism has been described elsewhere.¹ As originally conceived the device, which utilizes a welded metal bellows as a movable vacuum seal, has a lead screw as the means of obtaining linear motion. It is usually driven by flexible shaft and remote electric motor and gear unit appropriately called a Type IIID drive unit.² When plasma confinement time in the FM-1 machine was improved, faster acting mechanisms were requested. Pneumatic actuated devices were designed to meet the requirements and are currently used on the FM-1 machine.

II. PNEUMATIC PROBE POSITIONING MECHANISM

The IIIP mechanism was modified to accept a pneumatic cylinder as its means of actuation, see Fig. 1. The non-magnetic cylinder used is a double-acting, air return, front nose mounting cylinder with stainless steel rod and body, Buna N "U" cup seals and aluminum alloy porting ends. It is mounted on the rear end of the bellows housing in place of the usual lead screw and nut assembly, and is located on axis in line with the center line of the mechanism. The piston rod threads into the bellows end assembly, the design of which was changed for the purpose. Lubricated clean air is supplied to the cylinder at approximately 80 psig through standard rubber air hose. Exhaust air line is the same material. Air is controlled by use of a solenoid-operated four-way valve with built-in orifice restriction. The velocity of the piston, and therefore the probe, can be controlled by either adjusting the exhaust valve restriction or the air pressure, or a combination of both. The length of

stroke in the original design depends on the cylinder stroke. Later models incorporate an adjustable stop which allows selection of any length of stroke within the cylinder stroke.

The stop consists of a stainless steel nut and block driven along the underside of the bellows housing by a brass lead screw. It is guided in its travel for a distance equal to the cylinder stroke by two stainless steel rods. Friction between guide rods and block is minimized by use of oil-impregnated sintered bronze bushings pressed into the block. The ends of the rods are securely retained in blocks welded to the bellows housing. The lead screw rotates in bronze bearings located in these same blocks. A bored hole and drilled bleed hole in the stop block is half of a dashpot arrangement to provide cushioning effect.

Projecting out from the shuttle portion of the bellows end assembly is the piston half of the dashpot. When the mechanism is actuated, the moving shuttle comes in contact with, and is stopped by, the stationary nut and block. The dashpot cushions the shock. A Type IIID drive unit is attached to the lead screw through flexible shafting. Operation of the unit positions the stop where desired.

To provide a means of measuring a plasma parameter with respect to position of the probe while it is in motion, and over the entire length of its travel, a wire wound sliding contact resistor is provided. The resistor, slightly longer in length than the stroke of the mechanism, is fastened to the housing. The spring type beryllium copper sliding contact is screwed to the bellows end assembly and slides along the resistor as the probe moves. By use of the circuit shown in Fig. 2 an oscilloscope trace of position versus plasma parameter is obtained. The trace shown in the figure is ion saturation

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current versus position, and is in effect a plot of ion density for the portion of the plasma through which the probe travelled.

Figure 3 is a schematic wiring diagram of the control circuit used in the operation of the pneumatic probes. As the diagram indicates, there are several modes of operation. The probe can be inserted and withdrawn manually by push-button switch located on a panel in the machine control room. Operation can be fully automatic through use of the machine timer connections shown. Variable time delay on the retraction cycle, and combinations of manual and automatic operation are possible. All of the above combined with the feature of adjustable length of stroke provide a highly flexible and useful diagnostic tool.

III. PNEUMATIC CIRCUIT

The pneumatic circuit used in the operation of the probe mechanism and in the operation of devices to be described later consists of an accumulator and several air stations. Instrument-quality air is supplied to the accumulator at approximately 100 psig, and distributed from it to the air stations located around the machine base in positions of close proximity to the mechanisms. Each station serves a single device and has a pressure regulator with pressure gauge, a standard air line lubricator, and a four-way double solenoid valve. The valve is connected by a pair of air hoses to the cylinder.

IV. BALL FEED MECHANISM

The possibility of projecting a small ball or dart through a plasma to collect hot electrons has, for some time, been discussed as a means of observing the effect of high energy electrons on particle decay time. When longer confinement times were attained in the FM-1 machine,³ it became feasible to

drop a ball through, rather than shoot it through, the plasma. In order to observe the effect, the time of transit of the ball through the plasma must be relatively short compared to particle decay time. A 0.250 inch diameter aluminum ball takes approximately 200 msec to drop through the FM-1 machine plasma if dropped close to the levitated ring.⁴ Confinement times in excess of 1.5 sec have been recorded in this machine in recent experiments.

A pneumatic actuated device has been designed and fabricated to drop one ball at a time through the plasma. Since it is not desirable to open the machine to atmosphere to reload the device, it has been made to hold three hundred balls. Reloading is, therefore, not necessary until the magazine is empty. Figure 4 shows the ball-feed mechanism with its three-hundred shot magazine. It is fabricated from non-magnetic materials throughout. Static vacuum seals are "O" rings. The dynamic vacuum seal on the slide push-rod is a welded metal bellows. The pneumatic cylinder used here is the same non-magnetic type used on the probe mechanisms.

A collector, located directly under and in line with the feed mechanism barrel, was installed to catch the falling balls and prevent them from bouncing around inside the machine. It consisted of a short vertical tube with a funnel-shaped inlet, and a deflector plate in its lower end. The ball was deflected horizontally to a second plate where it was deflected downward into a collection chamber.

V. RING ROTATOR

One of the many safety features incorporated in the operation of the FM-1 machine is automatic catcher-closing⁵ if current in any of the

stabilization coils exceeds a preset limit. The current changes if the optical sensors⁶ (which are a part of the floating ring stabilization system)⁷ see more or less light as viewed over the optical edges on the ring. Since the edges are not perfect, the azimuthal variations in them cause current changes if for some reason the ring rotates. A particular orientation of the levitated ring has been found which results in minimum stabilization currents. Maintaining the ring in that position is very desirable.

When the ring drifts and the currents, which are carefully monitored by control room personnel, are observed to be approaching the predetermined limit, pulsing is discontinued and the ring rotator is used to return the still levitated ring to its preferred location.

Rotation of the ring by the rotator is accomplished by placing the rotator's diamond-knurlled 3 inch diameter aluminum wheel against the levitated ring, pushing against the ring with sufficient force to prevent any slipping, then rotating the wheel. The plane of the wheel and the plane of the ring are coincident.

The wheel, its 0.50 inch diameter stainless steel shaft, and a set of bevel gears all running on rulon bearings, are semi-enclosed in a housing mounted on the end of a one inch diameter stainless carrier tube. Welded to the other end of the carrier tube is a dual purpose flange. Attached by fusion weld to the forward side is the 8-inch stroke metal bellows which encloses the carrier tube and allows linear motion through the vacuum wall. Bolted to the after side is a "wobble" type⁸ rotary vacuum feedthrough. Coupled to the output end of the feedthrough is the drive shaft which extends through the flange and the carrier tube to the bevel gears in the wheel housing.

On the input end of the feedthrough a right angle drive, consisting of bevel gears, ball-bearings and shafts in a housing, is fastened. The housing is attached to the piston rod of the double-acting pneumatic cylinder used to provide the linear motion. The housing also has two slot-guided studs which prevent the housing and bellows from rotating. All the above is enclosed in a tubular bellows housing having a flange for mounting to the machine at one end and the pneumatic cylinder mounted at the other. A rulon bushing in the machine end flange and the front end bushing of the pneumatic cylinder support all the moving parts. Drive for the rotary motion is supplied by a 1/20th horsepower gearhead motor, remotely located, and attached to the above mentioned right angle drive by flexible shafting.

In the event of an air failure, atmospheric pressure on the effective area of the bellows would force the rotator into the ring. To prevent this, and insure fail-safe operation, two springs are used to apply a greater force in the opposite direction. The springs as well as the mechanism are shown in Fig. 5. Figure 6 is an assembly drawing indicating the major components of the device.

VI. SUMMARY

The mechanisms and systems described above are a portion of the many diagnostic tools employed in plasma research. These particular devices represent solutions to design problems which were best solved by use of pneumatic actuators. Although the use of pneumatics for actuation of mechanisms is not new to this or other laboratories, it is currently used at PPL for fast acting, remote-operated probe mechanisms and other devices. It provides clean,

non-magnetic, fast, relatively simple, and remotely controllable means of operating many types of mechanisms.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the most important contributions of S. W. Hand and M. J. Scott who were responsible for design and fabrication of the above-described devices. He also wishes to thank Drs. J. Sinnis, M. Okabayashi, and S. Yoshikawa for their most helpful suggestions. The excellent illustrations are the work of J. P. Motyka.

This work was supported by the U. S. Atomic Energy Commission Contract AT(11-1)-3073.

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Fig. 1. Pneumatic Operated IIIIP Probe Positioning Mechanism.

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Fig. 2. Schematic Diagram of Probe Signal Circuit and Oscilloscope Trace Produced.

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Fig. 3. Schematic Wiring Diagram of Control Circuit for Operation of Pneumatic Actuated Probe Mechanisms.

Fig. 4. Cutaway View of Ball Feed Mechanism

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Fig. 5. Ring Rotator

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Fig. 6. Outline Drawing of Ring Rotator

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