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# Very Fast Flow Control Techniques

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## Very Fast Flow Control Technique

**Advanced techniques for flow control are necessary for high pressure research on rocket propellants, where considerations of safety and stability dictate high response speeds.**

**Control systems based on conventional aircraft and missile components have been used to obtain a response of 50 to 10,000 cycles per second in large and small propellant apparatus. Examples of successful applications outline the performance to be expected of such systems and components in other applications. Operational experience with high dither stabilization as described by Oldenburger is reported.**

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# Very Fast Flow Control Techniques

## High speed controls for high pressure systems, resulting from work on rockets and jet engines, can be applied in the chemical industry

THE ROCKET INDUSTRY's activity in the field of high pressure is so little known that its interest in high speed controls for pressures above 10,000 pounds per square inch may be surprising. The extent is suggested, however, by the diversity of controls developed for application to rockets. Within the framework of response of 50 to 10,000 cycles per second, four examples of unusual controls indicate their use in the rocket industry and suggest their usefulness and performance in chemical applications: instant-action vent valve to generate pressure steps, proportional operator for complex arrays of large valves, letdown controller with essentially zero dead band, and "linearization" of controls by high dither techniques.

### Instant-Action Vent Valve

A valve of this type was needed in an ordnance research program. It appears to have use for analysis in the design o chemical plant.

In ordnance research, the instantaneous pressures within the gun barrel are significant, but are difficult to interpret from the data. In-place calibration of the pressure transducers is necessary to determine the frequency response of the measurement system. Perhaps the only feasible method for measuring the response of gun gages under pressures to 75,000 pounds per square inch involves the instantaneous release of breech pressures of accurately known value. If such a step pressure is completed ten times faster than the gage responds, the theory of pulses indicates that the record is a true picture of gage response. The problem then is essentially to devise a step pressure generator standard to release a series of precisely known breech pressures in essentially zero time.

Attempts to build an ideal step pressure generator never perfected signals that decayed in one tenth of the transducer period, for gun transducers are frequently capable of response to 160,000 cycles per second. Ideally, the standard would complete the release of pressure in less than 0.000001 second. A useful degree of success, however, was attained with a standard that incorporated an instant-action valve. Large air ports were provided above and below the diaphragm to maximize operating speed. Conventional use of a large four-way air valve direct-connected to an adequate air supply (50 to 100 pounds per square inch) resulted in time rates of pressure release as high as 100,000,000 pounds per square inch per second. On the basis of corrections for the effects of finite decay time, it is believed that the step pressure standard has generated steps with decay time of about 0.000007 second.

Many applications of such a response may not exist in the chemical industry, but in larger setups the response falls rapidly to values that might be useful. One suggested use is to block the propagation of detonative reactions which can be sensed upstream of the very high speed valve used here. The combination of valve and sensor appears to be feasible, as at least one transducer offers adequate response for frequencies as high as 250,000 cycles per second. The precision pressure isolator may be useful in some corrosive situations, but the response is highly dependent on careful filling.

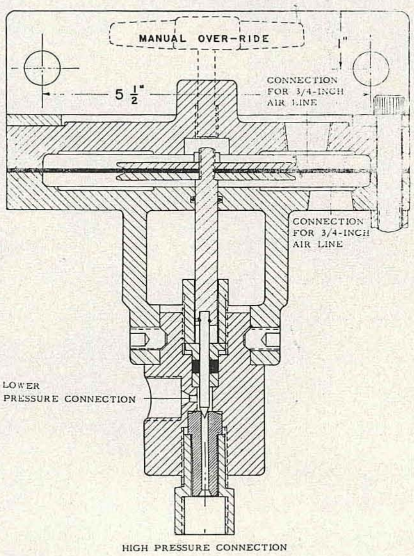
The instant-action valve has obvious use as a relief valve when connected to a suitable pressure-actuated pneumatic relay, and it offers the advantages of narrow differential and tight reseating. Its high speed ability would be wasted unless the reaction tends to run away and requires high speed venting to control that tendency.

### Proportional Operator for Complex Arrays of Large Valves

A second example of a high speed control occurred in the development of a chemically fueled power plant. An output rating just under 100,000 hp. required large valves (8-inch pipe size) to control the flow of propellants during start-up and in response to combustion pressure. The application cited was not intended to operate at 10,000 pounds per square inch, but the valve controllers developed for this application are equally usable for any processing pressure for which linear motion valves can be obtained.

Control specifications based on computer solutions required three main valves of different sizes, mutually synchronized to deliver propellants in burnable mixture ratios at all times and ultimately capable of 50 cycles per second response. The difficult specification was, however, that inaccuracies in relative flows of the three propellants must be controlled so that transient errors in relative flows integrate to zero in 1 second—to prevent accumulation of unburned propellants. The set of valves was further required to hold pressure within a few per cent of nominal in the presence of far larger magnitudes of disturbance—and again the error must integrate to zero within a few seconds. An 8-inch valve was the largest in the set.

The important component of this controller, which used hydraulic oil at 3000 pounds per square inch to drive the main process valves, was an electrohydraulic servo valve. Input signals of only 64 mw. deliver a full output of 60 gallons per minute. Complex signal networks are readily assembled to meet specifications, as the signal level is so low. The high output rating of the




**Critical component of the step pressure standard is the instant action valve**

valve, 100 hp. for low back-pressure loads, is capable of shifting even massive pipeline-sized valves. Responses to 50 cycles per second are not too difficult, as the hydraulic servo valve is itself responsive to frequencies approaching 100 cycles per second.

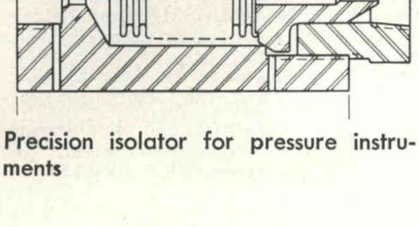
The resemblance between a power plant of this type and a large processing reactor suggests that high speed controls may be used to improve mixture ratios in reactors, to increase the margin of safety with reactions that tend to run away, and to reduce pressure and flow fluctuations in the processing plant. In the example cited, use of high speed controls permitted a striking reduction in the size of supply tanks, for the valves were fast enough to correct for the rapid decay in supply pressures which occurs at peak flow demand.

A similar controller for a smaller power plant eliminated pump and compressor surges that had previously required high pressure surge tanks.

### Letdown Controller with Essentially Zero Dead Band

A third application for high speed, high pressure control is in the letdown of reaction products produced in some highly energetic reactions. Speed may be important in such chemical processes for several reasons, such as very low tolerance for either pressure or flow fluctuations. In processes involving a high potential for explosive side reaction, control speed is dictated by safety. The example here involves both narrow tolerances and explosive tendencies and concerns a research train for the study of optimum parameters for the production of better propellants. The desire for more powerful rocket propellants implies directly that a better propellant contains an extreme of chemical energy, and as a rule, these advanced propellants are increasingly hazardous to handle even in small quantity.

**Approach to Problem.** Letdown specifications for this research plant were almost prohibitive, and four completely divergent approaches were required to find a solution. The specification called for a minimum response of 50 cycles per second, a leakage tightness equivalent to 0.0001-inch orifice, and a maximum flow area equivalent to 0.001-inch orifice. Even more critical was the requirement to throttle the flow smoothly



Precision isolator for pressure instruments

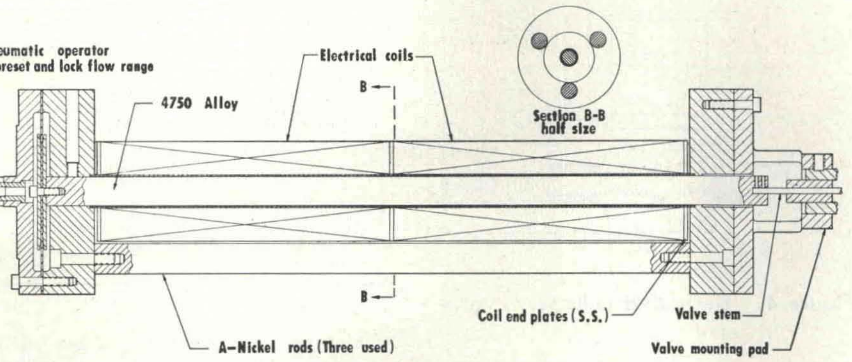



Figure 1. Magnetostriction valve operator

and repeatably anywhere in this range to a resolution of 1 part in 1000.

1. Commercial controllers with this resolution (but considerably larger ranges) were the obvious choice for initial work. All products tested were initially capable of meeting the leakage requirement; none held any promise as to response. Simple tests were made on-line: As the pressure built up to the set point, very little flow occurred; upon passing the set point of 10,000 pounds per square inch, the valve not only opened but completely vented the system, before it closed. In spite of the hazard of increasing the amount of potentially explosive intermediates, small surge tanks were installed, but were found useless.

2. A magnetostriction valve was designed. Although devices of this type were granted letters patent in the early 1800's, search for design data revealed little information. The valve shown in Figure 1 was evolved and tested in the laboratory. Just as the laboratory data looked promising, it became known that reaction products were condensing directly into solids as they left the catalyst region of the reactor. It was obvious that a successful valve would have to clear pellets 0.01-inch diameter rapidly, if upset were to be avoided. The magnetostriction valve held no hope of movements approaching 0.01 inch.

Although long-stroke magnetostriction devices were unknown at the time of those tests, a high speed, magnetostriction stepping motor was recently put on the market. Figure 2 shows that hydraulic clamps are sequenced to add the movements of separate magnetic pulses. (The device is currently incorporated in several milling machines where strokes of many inches may be required.) Study of its use in machinery for cybermation indicates that this device could be used to position valves requiring less than 300-pound thrust.

3. The pellet problem spurred interest in a third approach. The simple servo system (Figure 3) was put together in spite of theory which said it would oscillate. Stock aircraft components were used in this necessarily unstable circuit. In its first test on line, it held pressure so constant that variations could not be seen.

This control was considered successful, for it permitted collection of a minute sample before the letdown valve fell apart. In ensuing months, the life of letdown valves was a problem, being 5 to 10 minutes. Every trick was tried to reduce the destructive hammering of the letdown valve, to obtain longer life. Fourteen methods of stabilization were attempted, but in each case the valve stayed closed until pressure exceeded the set point and then completely vented the system. Alternative designs served no better.

The components of this system effected integral action, and the change in system pressure produced by a measured error was proportional to the time integral of the measured pressure error. The components included, first, a standard aircraft pressure transducer of the slide-wire type; its range was selected to be twice the desired operating pressure. A low voltage "filament"

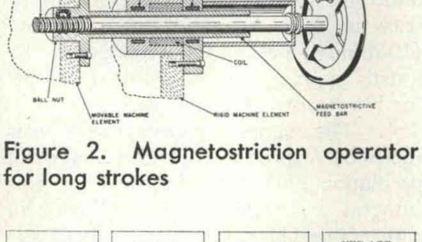



Figure 2. Magnetostriction operator for long strokes

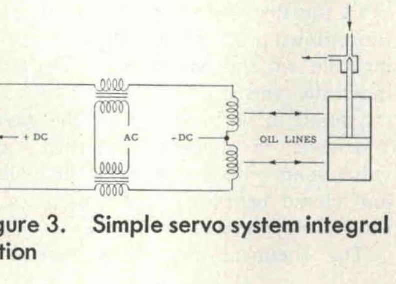



Figure 3. Simple servo system integral action

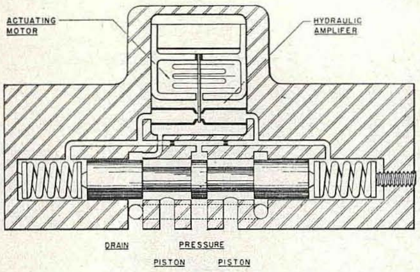



**Figure 4. Electrohydraulic servo valve**

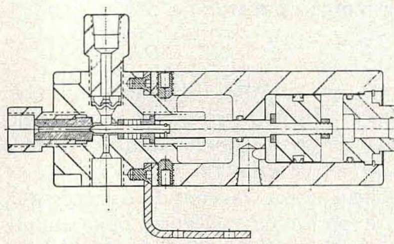


**Figure 5. Hydraulically actuated process valve**

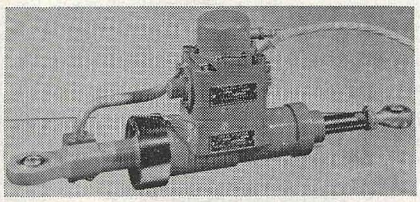


**Figure 6. Electrohydraulic valve positioner**

transformer was added to inject a small amount of "stick off" voltage, sometimes called "dither" voltage. The third component was an electrohydraulic servo valve of smaller and more customary size than the one shown above. The one used for letdown control (Figure 4) was rated at 6 gallons per minute.

The high temperature, high pressure, and high speed letdown valve (Figure 5) was the most successful of any tested (10-minute life). It was used in the fourth approach, where limited operating life ceased to be a problem.

4. The simple servo system was modified to produce a higher degree of oscillation than was inherent in this integral controller. The amount of dither injected was 5 to 10 times the direct current signal which produced full output.

In the first tests with this controller, the letdown problems vanished. Operating life of the valve was essentially indefinite and pressure deviations were too small to be indicated by the gages. Whenever a pellet condensed, the valve snapped open, passed the pellet, and closed before the reaction pressure showed appreciable deviation.

The chemical uses for a control of this type are obvious. One useful component has not, however, been mentioned. Figure 6 shows an electrohydraulic positioner, which incorporates the same servo valve in a package with an integral hydraulic ram. The latter corresponds to the hydraulic actuator which is otherwise part of the process valve. This package also includes a sealed slide-wire to indicate position of the ram which would be directly connected to the process valve stem. This position feedback signal offers many more circuit possibilities than the simple servo system particularly to achieve true proportional control action in which the valve position is proportional to pressure error.

**Table I. Relative Importance of Speed of Control for Various Reactions**

| Tolerance for Reaction Fluctuations | Sensitivity (Explosion Hazard) | System Compressibility | Relative Need for Speed |
|---|---|---|---|
| Any | High | Any | Required for safety |
| Narrow | Moderate | Hard | Required for operation |
| Wide | Moderate | Hard | Convenient or economic |
| Narrow | Moderate | Soft | Convenient |
| Wide | Low | Soft | Not recommended |

## Linearization of Controls by High Dither Techniques

The usefulness of high amplitude dither was recognized by Oldenburger (1) to provide satisfactory stabilization in hydraulic control systems of the high dither type. Successful application for several other control problems has shown, further, that Hither is a powerful tool with more than one use in the control field.

Pertinent design criteria include the following:

The use of Hither may be indicated when controllers oscillate wildly and when the maximum gain for stable operation fails to hold the deviation within tolerable limits.

The magnitude of alternating current ampere-turns in the servo valve coil should be 5 to 10 times greater than the direct current ampere-turns required to saturate the servo valve.

The frequency of Hither should be much higher than the frequency of self-oscillation in its absence.

The frequency of Hither must not be so high that any element of the hydraulic amplifier ceases to move.

Vibration of the stem of the process valve should be invisible, but discernible by touch.

Satisfactory operation in closed loops can be obtained at higher signal frequencies when Hither is used.

## Summary of Response and Needs for Speed

The responses achieved with the controls described are somewhat higher than their nominal ratings, as maximum outputs are seldom required at the small strokes of high pressure valves. Estimated and small signal responses for the components illustrated have been tabulated to serve as a guide for the initial selection of control techniques for new applications.

**Ultimate Response Capabilities of Selected Components**

| Title | Pertinent Ratings, Lb./Sq. Inch | Response, Cycles/Sec. |
|---|---|---|
| Instant-action shutoff valve | 130,000 | 7 µs. |
| High frequency pressure transducer | 25,000 (adapter) | 250,000 |
| Precision pressure isolator | 30,000 | 250 (est.) |
| Servo valve for large plants | 60 gal./min. | 82 |
| Magnetostriction valve operator | (1000-lb. thrust) (0.001-inch stroke) | 10,000 (est.) |
| Magnetostriction motor | 300-lb. thrust | 50 (est.) |
| Simple servo system | 6–60 gal./min. | 190 |
| Electrohydraulic servo valve | 6 gal./min. | 190 |
| Hydraulically actuated valve | 30,000 | 200 (est.) |
| Electrohydraulic positioner | 300-lb. thrust | 65 |

The names applied to the controls and examples indicate where high speed controls have been used by the rocket industry. Requirements for speed of control are similar in both fields. Table I tabulates the reaction properties that influence relative requirements for high speed controls.

## Literature Cited

(1) Oldenburger, Rufus, "Signal Stabilization of a Control System," ASME Paper 56-A-92, ASME Annual Meeting, New York, Nov. 25 to 30, 1956.

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