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An Experimental Investigation of the Aerodynamics of a Disc Valve

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AN EXPERIMENTAL INVESTIGATION OF THE AERODYNAMICS OF A DISC VALVE

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ABSTRACT

The object of this study is a disc valve. In particular, the transient behaviour of the valve is studied as the valve moves from being fully closed and sealed to being fully open with steady-state flow of air established. The steady-state behaviour is well researched, the transient behaviour less so. A common assumption in valve design is that transient valve behaviour can be accurately represented by steady-state flow at fixed increments of valve lift. This assumption was shown to be incorrect at the early stages of valve lift by earlier work (1,3).

INTRODUCTION

Earlier work (1) indicated that the normal force exerted on a disc valve by the air during transient motion was significantly different from the force experienced by the valve due to steady-state flow through the valve at fixed increments of valve lift, for low values of valve lift. In addition, the gas force on the valve was shown to pass through a minimum before settling at a final steady-state value. The work of Schrenk on the flow of water was recalled (2) in which he demonstrated that the flow adhered to the valve seat up to a critical value of valve lift, at which instant the adhered "coanda" type flow was abruptly ended by the flow being torn off the seat and flipping up through 30^{o} to 40^{o} as a distinct jet, entraining the stiller fluid around it as it did so. At larger values of valve lift during transient motion, force and flow patterns are established which are not significantly different from those due to steady-state flow through the valve at fixed increments of valve lift. The authors of this paper have been conducting an experimental investigation of these phenomena and this paper reports in general terms the outcome of their work to date.

THE VALVE TEST RIG

The earliest tests (1) were carried out using a moving seat/fixed disc rig. The (relative) disc rise rates attained in this rig were considerably slower than the rates at which pressure actuated valves actually rise in compressors during normal operation, so a second rig was designed and built with a light moving disc assembly which is pulled away from a fixed seat during a transient test to release the compressed air contained in the plenum chamber (Fig. 1). Much higher rise rates are achieved with this rig; indeed the rise rates are thought to be realistic.

The system for measuring the normal gas force on the valve disc was reported to this Conference in 1980 (3) and will not be described in detail again here. It is sufficient to say that it depended on two "identical" Kistler force transducers being mounted back to back so that when their signals were electrically summated, the unwanted signal from the main force transducer due to the acceleration of the assembly during the transient motion, was nullified by an acceleration signal which was equal in magnitude but opposite in sign from the compensating force transducer.

A transient test is carried out by firstly supplying current to the electro-mechanical actuator to hold the disc down on the seat against the action of the pre-compressed spring (Fig. 1). The plenum pressure is charged with air to a pressure in the range 6 to 15 psi, values thought to be typical of the pressure differences that develop across compressor valves in service. When the current to the actuator is suddenly switched off, the pre-compressed spring pulls the valve from the seat releasing the air to atmosphere. Hot wires mounted in close proximity to the valve disc measure the air flow in magnitude at all stations and in direction at some.

THE TRANSIENT TESTS

Hardware

A four-channel data acquisition system was put together by making use of two two-channel digital storage oscilloscopes. The oscilloscopes were synchronised in time by triggering them both externally by the same pulse; the pulse being generated by a third oscilloscope when the output level of the displacement measuring system voltage reached a suitable value. The triggering system is adjusted to fire the oscilloscopes on the same digital time-base register on each oscilloscope, so that the stored information in both oscilloscopes associated with that register relates to four simultaneous events. The information associated with all other corresponding pairs of time-base registers is only simultaneous if the time-base speeds are equal to a high degree of accuracy. When a pair of oscilloscopes are used which have unequal time-base speeds (they could differ by up to 6%) the speeds are measured and software is written to shuffle the data from the faster oscilloscope to associate it with the "correct" corresponding registers in the slower oscilloscope.

The stored signals were digitised and stored on tape for subsequent computer analysis and graph plotting etc.

The four-channel system thus acquired is used to make transient recordings of the signals from:

1. the valve disc displacement system,

2. the gas force measuring system,

3.) two hot wires in a X-wire formation.
4.)

Recordings were also made on a single oscilloscope to determine the relationship between disc displacement and the magnitude of the mean air velocity at chosen stations. A boundary layer probe with the wire mounted normal to a radial plane was used for this purpose.

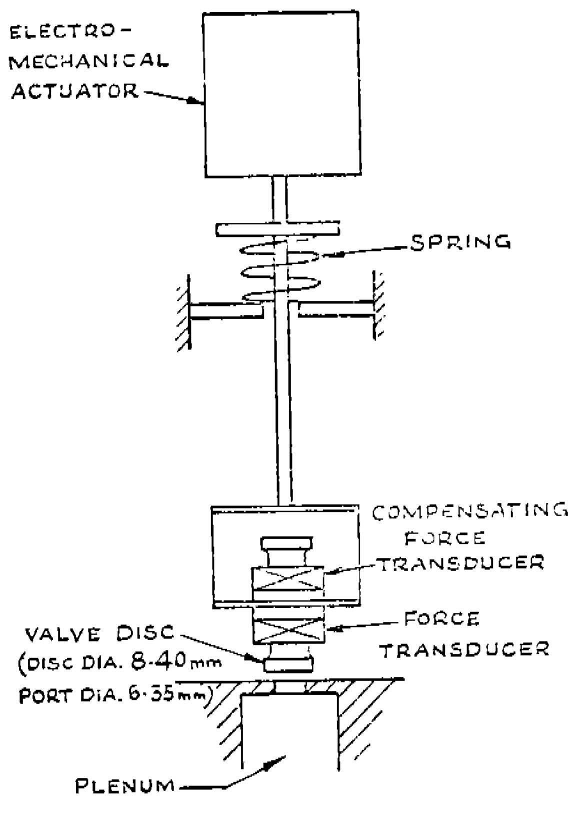

FIG. 1. DIAGRAM OF TEST RIG

The direction of the mean flow can be determined at a particular station if the boundary layer probe is removed and replaced by a X-wire probe with the centre of the X-wires on the station previously occupied by the boundary layer wire.

ASSUMPTIONS

Cylindrical symmetry is assumed for the pattern of the mean air flow from the valve at all times. All tests which have the same displacement versus time curve are (nominally) identical; i.e. the only non-identical feature of "identical" tests is the detailed behaviour of the turbulence. This implies that at a given valve lift in identical tests, the magnitude and direction of the mean velocity of the air are always the same.

Mean values of hot wire anemometer traces were attained by making a number of identical tests and averaging the data. At stations fairly low in turbulence as few as ten records were sufficient to get acceptable mean values.

It is assumed that the air flow pattern is determined by the geometry of the passage through which the air flows and its variation with time. In other words, the fact that the disc is being pulled off the seat by a spring and not pushed off by the escaping air is taken as making no difference to the air flow pattern.

CALIBRATION OF THE HOT WIRES

Calibration curves for the hot wires were obtained by recording their bridge output signals when the wires were subjected to the flow of air from a standard nozzle. The signal from a pressure transducer mounted upstream of the nozzle was displayed on one channel of a storage oscilloscope while the wire signal was displayed on the other. The pressure (air velocity) was slowly increased in magnitude from zero to a suitable maximum value and then the storage button was pressed. In the case of the X-wire, two storage oscilloscopes were used with the pressure signal being displayed simultaneously on channel A of both oscilloscopes while channel B of the first oscilloscope displayed one of the X-wire signals and channel B of the second oscilloscope displayed the other X-wire signal. The X-wire assembly was held in a swivelling arrangement which allowed the probe shanks to be orientated in relation to the jet axis at any angle in the range -80^{o} to $+90^{o}$. Calibration curves were produced at 10^{o} intervals, i.e. 18 curves in all.

The data for the X-wires rearranged as curves of constant velocity magnitude against angle of flow are shown in Fig. 2 for the downward facing wire (i.e. in relation to the valve seat) and in Fig. 3 for the upward facing wire. Fig. 4 shows a diagram of the X-wires and valve to the same scale.

A knowledge of the ratio of the X-wire outputs is a useful aid in interpreting X-wire signals. This data is displayed in Fig 5 as the same family of velocity magnitude curves used in Figs 2 and 3.

The ratio up wire output to down wire output against angle of flow is shown.

MEASUREMENTS OF VALVE TRANSIENTS

Fig 6 shows two boundary layer probe traces obtained at stations close to the valve seat (stations 1 and 2, Fig 4). These traces at stations 0.25 mm up from the valve seat should be compared with the traces shown in Fig 7 obtained at much higher (3 & 4) stations, 1.27 mm up from the seat but at the same distances out from the valve disc edge (4.0 mm and 8.9 mm). The Fig. 7 traces seem to indicate that a jet of air has detached from top of the layer of air flowing along the valve seat and swept up through quite a large angle; and in so doing has swept onto and above the sensing wire of the probe to give the rise and fall shape clearly seen in the traces.

An attempt was made to investigate this phenomenon by making a number of "identical" traces and averaging the data to smooth out the turbulence and give signals which represent the mean velocity. This was done with both the boundary layer probe traces to determine the variation of mean velocity <u>magnitude</u> and also with the X-wire traces to determine the variation of the angle of the mean velocity.

Fig.8 shows a boundary layer mean trace produced in this way and Fig.9 shows X-wire traces similarly produced.

When an attempt is made to calculate angles of flow from this data, it fails because the X-wire probe voltages are too low. This is probably due to the thickness of the jet which is passing over the wires i.e. it is very thin and much smaller in thickness than the wires are in length. The wire calibration curves were determined by subjecting the wires to flow of a known velocity over their complete lengths. As a result, flow over part of a wire length can not be interpreted quantitatively.

However the indications that a phenomenon of the type described is occurring are strong. It is difficult to explain the shape of the X-wire traces in any other way.

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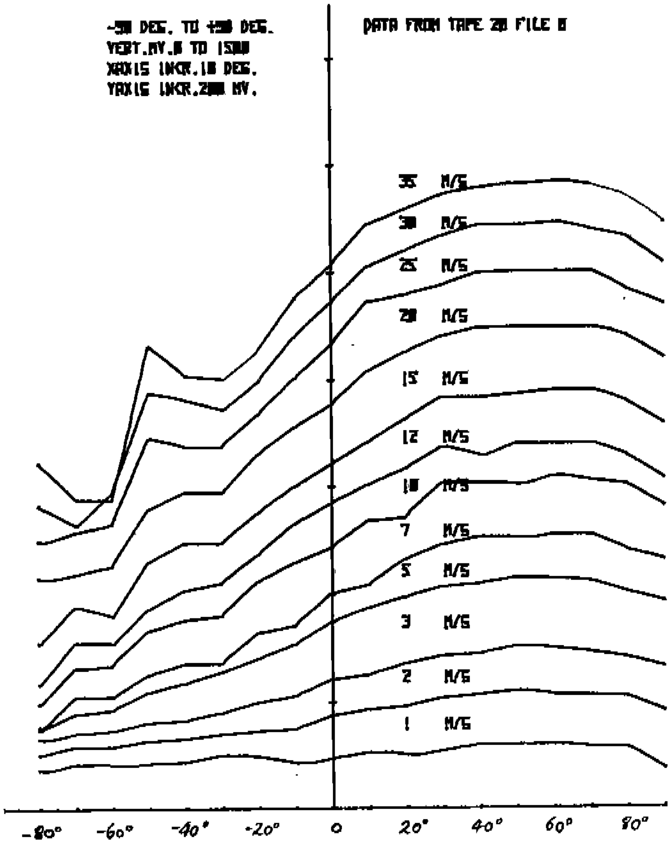

FIG 2. CALIBRATION CURVES

'DOWN' WIRE

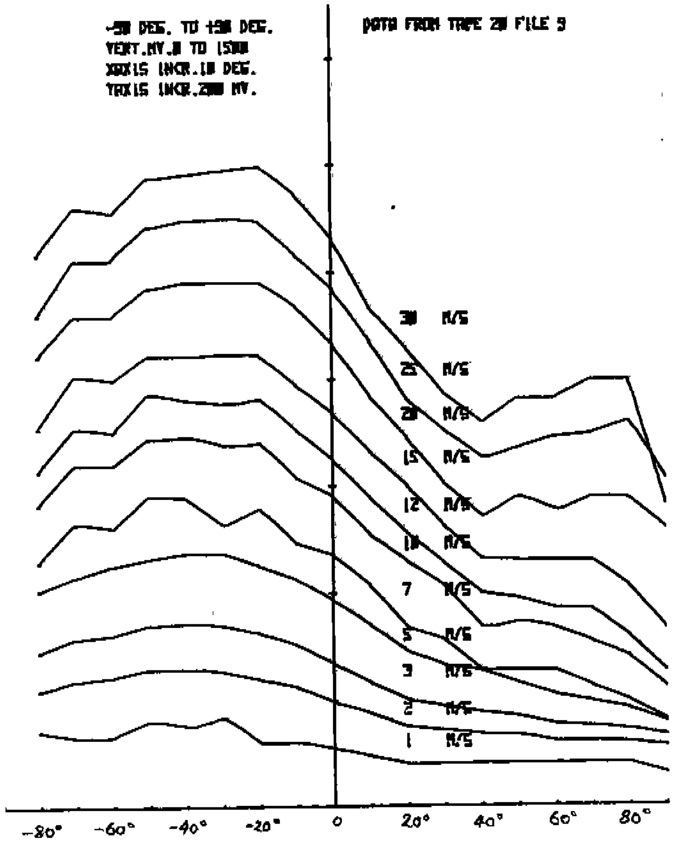

FIG 3. CALIBRATION CURVES

'UP' WIRE

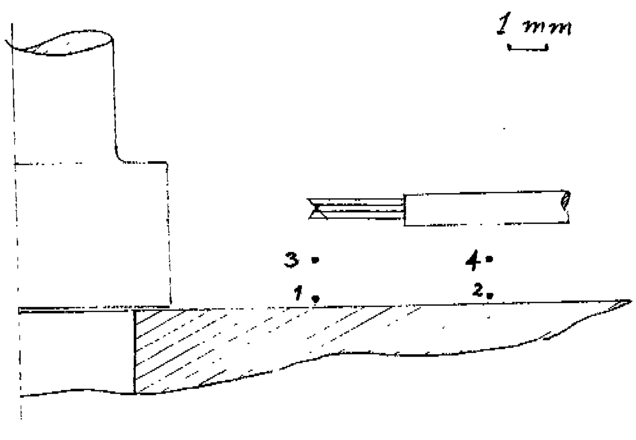

Fig 4 Valve & X-Probe

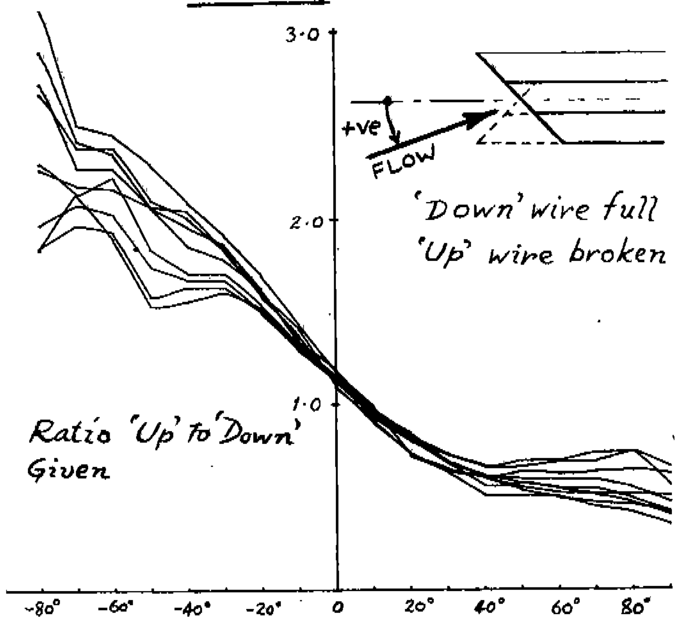

FIG 5. CALIBRATION CURVES

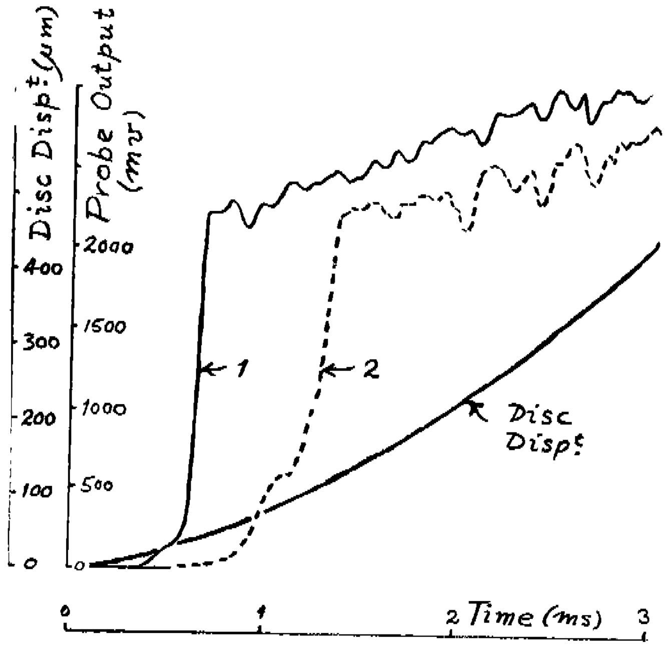

FIG 6 BOUNDARY LAYER PROBE TRACES (Stations 1 & 2)

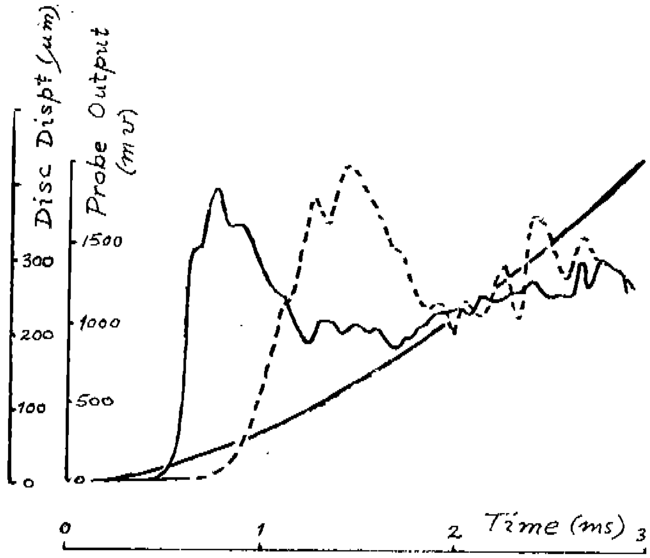

FIG 7 BOUNDARY LAYER PROBE TRACES (Stations 3 & 4)

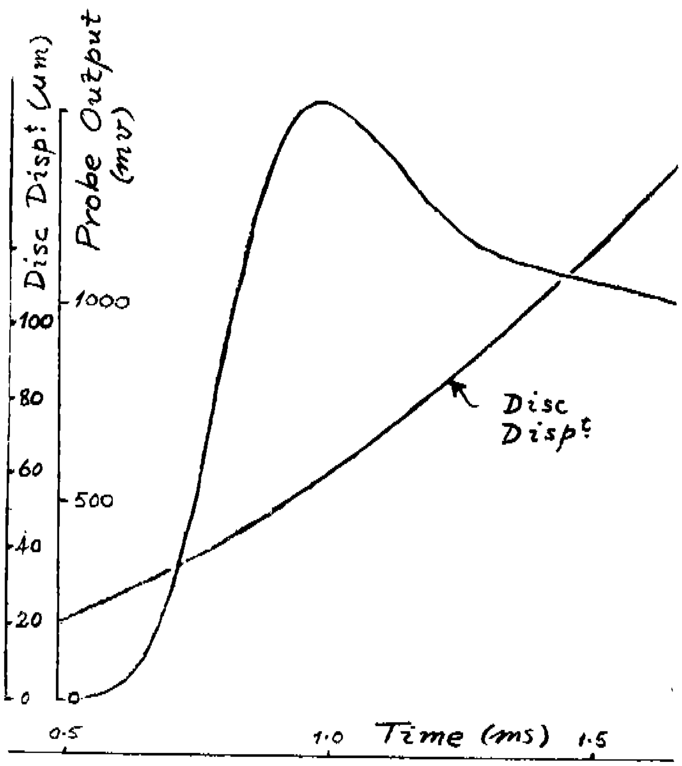

FIG 8 BOUNDARY LAYER PROBE MEAN TRACE (Station 3)

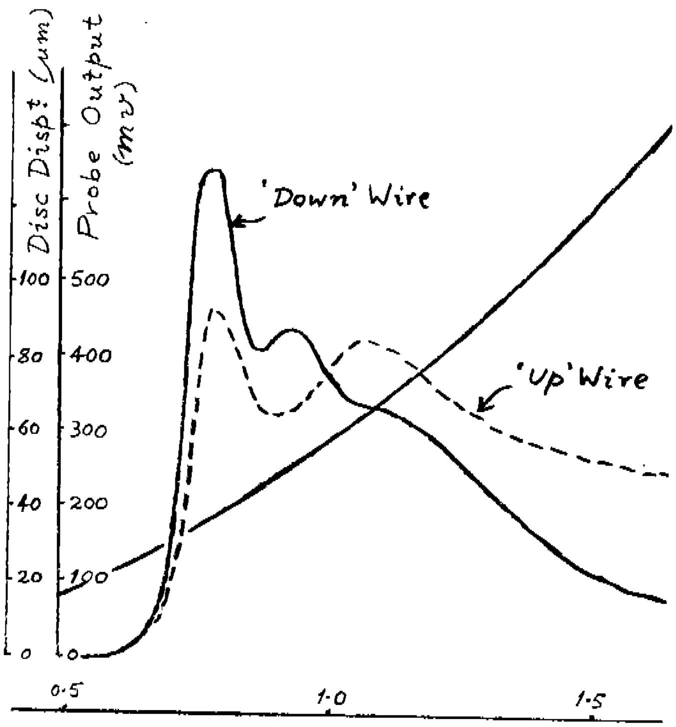

FIG 9 X-WIRE PROBE MEAN TRACES (Station 3)