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J. Brown
University of Strathclyde

A. Lough
University of Strathclyde

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AN EXPERIMENTAL INVESTIGATION INTO THE RESPONSE OF DISC VALVES TO RAPID PRESSURE CHANGES

J. Brown, B.Sc., Ph.D., A.R.C.S.T., C.Eng., M.I.Mech.E., F.Inst.R.
Reader in Dynamics and Control, University of Strathclyde, Glasgow.

A. Lough, B.Sc., Ph.D., Senior Lecturer in Design and Drawing,
University of Strathclyde, Glasgow.

ABSTRACT

The paper describes tests carried out on disc valves of varying thickness and operating on seats of different profile when subjected to sudden changes of pressure across the valve. These changes of pressure were produced in a shock tube 50 mm in diameter. The high pressure chamber was 0.6 m long, while the low pressure chamber was 2.125 m long. A drum camera, synchronised to the pressure pulse, was used to record the response of a particular disc under examination. A quartz piezo-electric pressure transducer was used as the standard against which the displacement of a valve disc was compared. It is shown that an optimum disc thickness may be arrived at when considering the time response of the disc valves to these shock pressure changes. This optimum value of disc thickness is virtually independent of seat profile. It is also shown that valves with large seat area have faster response times to rapid pressure changes than valves operating on sharp-edged seats. A complementary series of tests was carried out in an air compressor where oil was present in the air passing through the valves. These tests showed that the benefits gained by valves whose seats had a large surface area were offset by oil-stiction effects. In these circumstances, valves whose seat profile approach knife-edges are recommended. It is hoped that dynamic tests carried out under such controlled conditions will enable parameters such as dynamic drag coefficients etc., to be derived without the necessity of making assumptions regarding the relative importance of other parameters which affect valve behaviour under normal working conditions in a compressor. Future work will involve an extension of these tests with rates of pressure rise across the valve which are of the same order as those encountered in the field. A laser technique which has been used to examine the deformation due to temperature in the diaphragms of pressure transducers is outlined in the paper. This technique will be used to determine the attitude of valves on their seats with a view to obtaining an accurate assessment of surface stresses at impact.

INTRODUCTION

The practical investigation of the dynamic characteristics of thin disc valves described in this paper was initiated as a result of work carried out previously by Lough (1) on the general behaviour of the balanced-disc type of pressure transducer. This transducer was being used as a research tool whereby the sensitivity of diaphragm-type pressure transducers to transient thermal interference could be assessed.

An experimental balanced-disc transducer used in this connection is shown in Fig. (1). The essential feature of this type of trandsducer is that the thin disc, shown in the diagram, is able to move between valve seats whenever a pressure differential exists across the disc. When the transducer is screwed into the cylinder head of an engine or compressor, one side of the disc is exposed to the fluctuating pressure of the working fluid, while the other side is exposed to a predetermined constant or "balance" pressure. The disc moves from one seat to the other at two points in the working cycle. Movement of the disc is detected electronically and the pulses produced can be used to "pin-point" the continuous output waveform of a diaphragm pressure transducer. Any errors in the waveform due to distortion of the diaphragm brought about by transient thermal or other interfering inputs can be detected.

The main virtue of the balanced-disc transducer is that it is insensitive to temperature and other sources of interference. Its performance is somewhat analogous to a "feed-back" system such as the constant temperature hot-wire anemometer shown schematically in Fig. 2a. The hot-wire or film sensor of the anemometer is not required to follow variations in environmental temperature to which it is exposed. Similarly, the balanced-disc does not require to follow the pressure excursions encountered in the cylinder.

The method of building up pressure-time or crank angle diagrams is illustrated in Fig. 3a along with a diagram produced by a diaphragm-type transducer (3b). This shows differences in output from the two transducers as a time or crank-angle delay at selected balance pressures.

It was of course essential that the reliability of such balanced-disc transducers be proved since some investigators including Bruffell (2) have claimed that the differences in output described above are due to deficiencies in the performance of balanced-disc transducers. A shock tube was used to provide short rise-time pressure changes across the disc valve of the transducer so that its time response and reproducibility of output could be assessed. Fig. 4 shows the shock tube and its associated instrumentation. A piezo-electric transducer was used as a datum for the determination of possible time lags in the outputs of the experimental transducers. Fig. 2b is a typical oscillogram showing the simultaneous responses of these transducers to the rapid pressure change generated in the shock tube.

These tests showed the high degree of reproducibility and reliability of the experimental transducers. It was quickly realised that the technique being used could be extended to investigate in a more comprehensive manner the behaviour of automatic valves in a dynamic situation in which the parameters could be controlled more effectively than in a working compressor.

DYNAMIC RESPONSE OF THIN DISC VALVES

The reliability tests on the balanced-disc transducer were followed by preliminary experiments to determine the effects of the variation in the design of disc valves. Steel discs of 12.5 mm diameter and varying in thickness from 0.125 to 1.00 mm were placed in a special test mounting. This was located in the end of the shock tube and was subjected to step pressure changes when the brass diaphragm in the shock tube was ruptured. The response of the piezo-electric transducer to the first impulse of the pressure wave was taken as the reference with which all other time responses were compared. The influence which the shape of the valve seat has on response was also considered. Both "knife-edge" and wide flat seats were tested and the valve responses to the step inputs in both cases were examined. Vibration interference in the test rig was minimised by using suitable resilient anti-vibration rings to isolate the valve unit from the main body of the shock tube. It will be noted from Fig. 2b that the shock transmitted along the metal of the tube and apparent in the output of the piezo-electric transducer is absent in the output of the experimental balanced-disc transducer which utilised the same mounting as the experimental disc valves.

The responses of the various disc valves to a step input of pressure are shown in Fig. 5. The time lags indicated are relative to the piezo-electric transducer and are drawn to a base of disc thickness. The graphs show the responses of knife-edged seated and flat seated valves. It is evident that discs operating on flat seats are appreciably faster in response than those operating on knife edges. An optimum thickness of disc obtains for both seat configurations with discs of around 0.042 inches. This would seem to infer that the optimum response is a function only of disc thickness for a given type of seat. The graph also shows that the two curves converge as the disc thickness is reduced.

The probable explanation for the performance of the valves when subjected to variation in the parameters of disc thickness and seat configuration is outlined below.

The effect of gravity on disc response can usually be neglected. However the effect of disc mass becomes obvious as disc thickness is increased becoming the dominant parameter for very thick discs as shown by the increased time lags for discs greater than 0.042". Fig. 6 shows the probable distribution of pressure for the two seat configuration chosen. The figure shows back-seated valves as used in the early balanced-disc transducer tests. The form of the pressure distribution across the flat seat is assumed and obviously depends on the flexibility of the disc. The deflection of a very thin disc will cause the disc to bear only on the inner edge of the flat seat giving effectively the same pressure distribution as a valve fitted with knife-edged seats. This is confirmed by the convergence of the two graphs in Fig. 5. It will be noted that the force due to the pressure difference across the valve is greater in the case of the flat-seated valve than for the knife-edge valve where the port diameter is the same for both valves. This was the arrangement in these experiments. When the pressure across the flat-seated valve is suddenly equalised, the pressure difference ($P_2 - P_1$), which might be thought of as the "gasket" pressure, still exists across the seat area. Hence there is a positive retention of the disc on the seat. This would imply that the flat-seated valve would have a longer delay than the knife-edged valve. The experimental results do not support this theory. Hence we conclude that the effect is very small for the conditions of these tests but future experiments will be designed where the influence of this parameter is more pronounced. It is obvious that other parameters assume greater importance, and among these is the existence of a thin film of gas between the seat and the disc due to its deflection under pressure. The assumption that the gasket pressure remains constant during the application of the sudden pressure change across the valve is therefore not valid and the change in curvature of the disc increases the mean pressure between the valve and the seat causing a more rapid lift of the valve from the seat. Fig. 7 shows the probable distribution of pressure across the seats of valves fitted with thick and thin discs. A greater force will therefore be generated by the gas cushion under the thick disc assisting its initial lift from the seat. This hypothesis therefore provides an explanation not only of the more rapid response of thick discs compared to thin discs on wide seats but also explains the slower response of narrow seated valves since the gas cushion is negligible in this case. The increase in the time response of the valve as the seat thickness is reduced to a very low figure is caused by the excessive flexure of the valve leading to a strain energy release pattern complicated by the overhang on the valve seat.

The time lags measured are very small but,in a compressor,oil will almost inevitably be present which has a modifying effect on valve behaviour. Fig. 8 shows simultaneous records produced by two similar balanced-disc pressure transducers. It will be observed that the transducers exhibited a reasonably identical output at the beginning of the test when the seats were dry (diagram 8a) but, after some time, when oil had seeped on to the seats, the disc for the flat-seated transducer left its seat 18 ms after the disc in the knife-edge seated transducer (diagram 8b). The presence of oil on the seats was noted by visual examination after dismantling the transducer. It is possibly of interest to users of such transducers that, while flat-seated transducers might well be satisfactory for I.C. engine work, the knife-edge seated transducer is to be preferred in experimental compressor work. Incidentally, for the same reason, a very short passage to the transducer is desirable to prevent a build up of oil in the passage which renders the transducer inoperative.

DEFLECTION OF CLAMPED DIAPHRAGMS

The technique described in this section was developed in order to examine the deformation of the diaphragms of pressure transducers due to transient temperature interference but is applicable for the study of automatic valves which are clamped such as reed valves or crescent valves. In this context it should be noted that the temperature interference experienced by pressure transducers is also experienced by these valves. Hence the deflected form of a reed valve may be influenced by thermal stress to a not inconsiderable extent. Fig. 9 shows the instantaneous temperature distribution across thin diaphragms whose thermoelastic properties are widely different. These temperature distribitions were deduced from an electrothermal analogue of the diaphragm. It will be observed that large temperature gradients exist at the periphery where the diaphragms are clamped. Theoretical studies show that such temperature gradients can produce considerable bending of the material which should be taken into account when analysing the behaviour of systems of this kind. The magnitude of these effects is dependent on many parameters such as the thermal properties of the diaphragm and the associated clamp and the heat transfer conditions at the surfaces.

To investigate these phenomena it is necessary to study the deflected form of the specimen, and laser holography affords a convenient technique for this. For transient or cyclical phenomena, time-averaged holography is of limited value compared to stroboscopic holography. Stroboscopic holography enables the deflected forms to be "frozen" at any instant during a transient or cycle. Fig. 10 shows a line diagram of the laser holography employed to examine the deflections of mild steel and stainless steel diaphragms under cyclical pressure and temperature excitation. Fig. 11 shows a typical recording of the simultaneous holograms produced from identical mild steel and stainless steel discs. The obvious difference in deflection shown by the fringe patterns is caused by thermal stressing already discussed.

COMMENTS

As previously mentioned, these techniques were developed for instrumentation studies and these are described in a contribution to the Joint British Committee for Stress Analysis (3). These techniques are now being employed to examine different types of compressor valves in a dynamic situation divorced from the actual compressor. It is hoped to correlate the information gained from this programme with work carried out using similar components in gas and refrigeration compressors and also to assist in the further development of computer programmes compiled for the study of automatic compressor valves.

ACKNOWLEDGEMENTS

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REFERENCES

1. Lough, A.L., The Accuracy of Transducers in Refrigeration Research, Thesis for Ph.D., University of Strathclyde, 1972.

2. Bruffell, W.K., Electronics Applied to Medium-speed Engines, Symposium, Institution of Mechanical Engineers, January 1966.

3. Lough, A. and Brown, J., A Qualitative Analysis of the Transient Thermal Sensitivity of Pressure Transducers, Conference Joint British Committee for Stress Analysis Inst. of Marine Eng. April 1972.

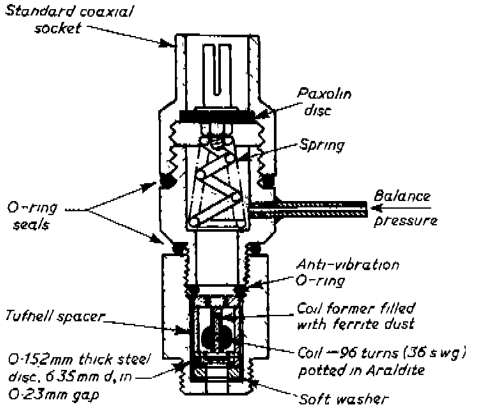


FIG. 1. —*Balanced-disc inductive pressure transducer (full size)*

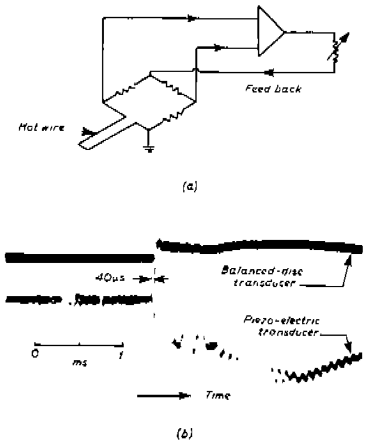


FIG. 2—*(a) Constant temperature hot-wire anemometer illustrating principle of feed-back (b) shock-tube responses of balanced-disc and "Kistler" piezo-electric transducer*

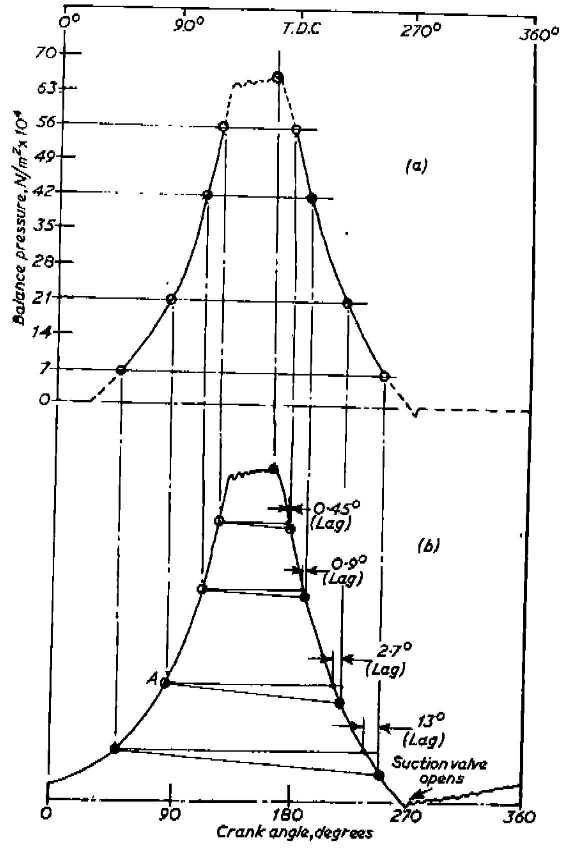


FIG. 3. —*Test No. 252, speed, 600 rev/min: (a) pressure diagram built up from balanced-disc transducer (b) pressure diagram measured by silver steel transducer with diaphragm 12·5 mm d, 0·4 mm thick*

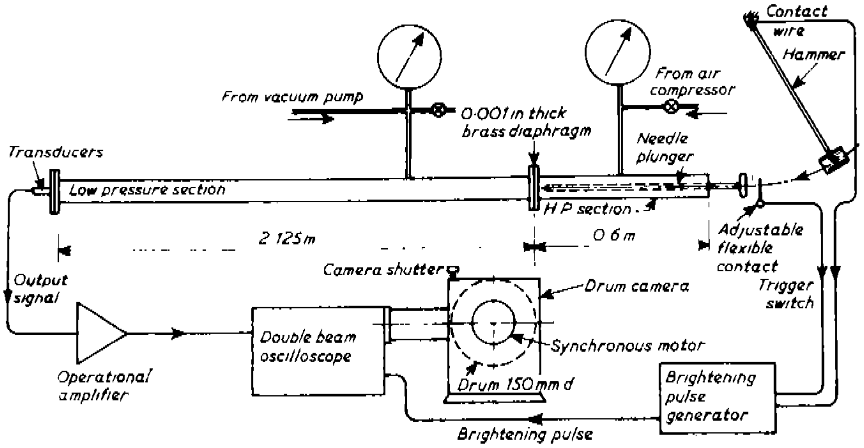

Contact wire
Hammer
From air compressor
From vacuum pump
0·001 in thick brass diaphragm
Needle plunger
Transducers
Low pressure section
H P section
2 125 m
0 6 m
Adjustable flexible contact
Trigger switch
Output signal
Camera shutter
Drum camera
Double beam oscilloscope
Synchronous motor
Operational amplifier
Drum 150 mm d
Brightening pulse generator
Brightening pulse

FIG. 4.

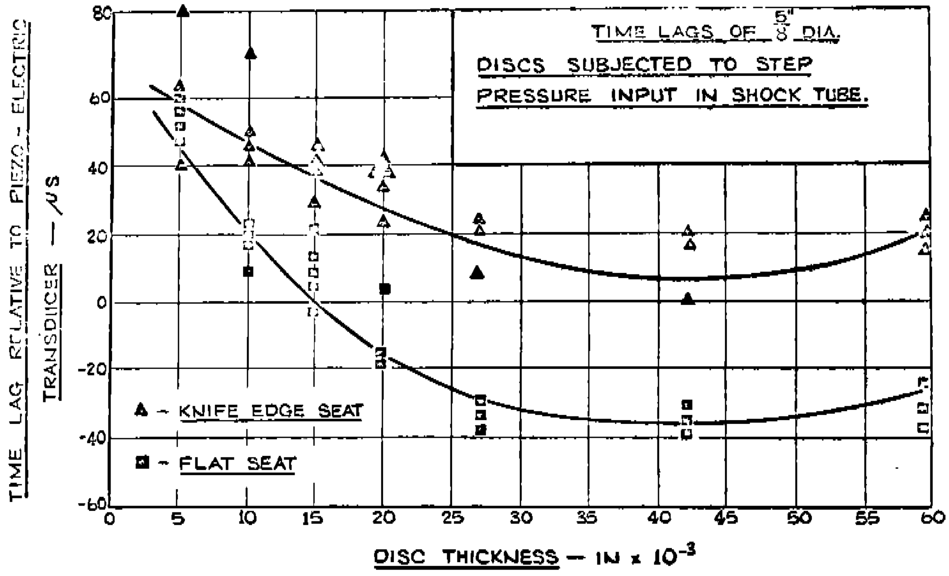

TIME LAGS OF 5/8" DIA. DISCS SUBJECTED TO STEP PRESSURE INPUT IN SHOCK TUBE.
▲ – KNIFE EDGE SEAT
■ – FLAT SEAT
TIME LAG RELATIVE TO PIEZO - ELECTRIC TRANSDUCER — μS
80
60
40
20
0
-20
-40
-60
0
5
10
15
20
25
30
35
40
45
50
55
60
DISC THICKNESS — IN x 10^{-3}

FIG. 5.

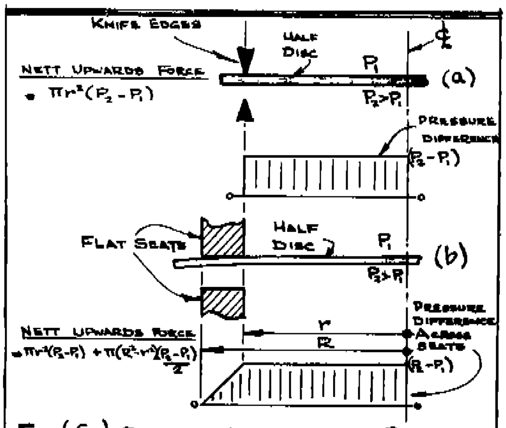
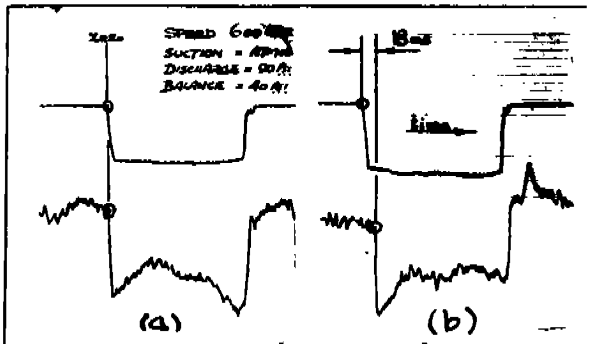
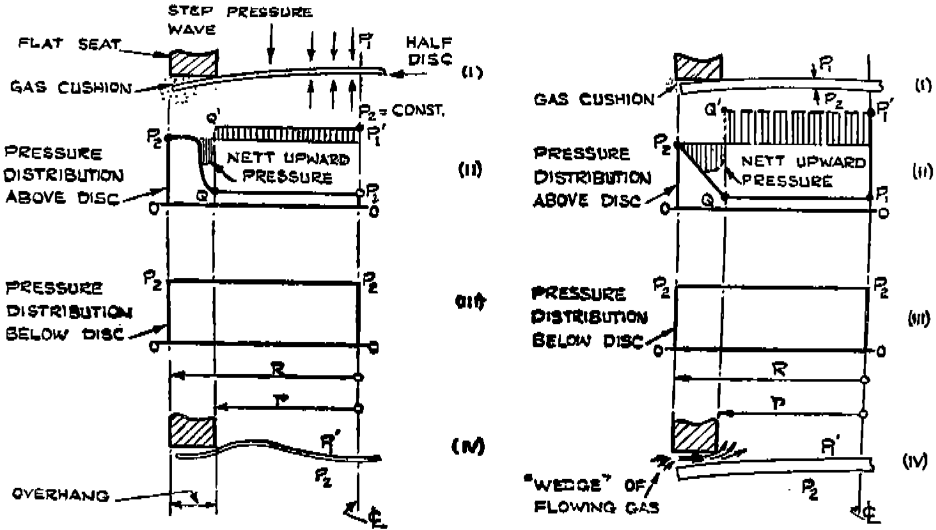


FIG. (6) PRESSURE DISTRIBUTIONS FOR KNIFE-EDGED AND FLAT SEATS.



UPPER TRACES — "KNIFE-EDGE" TRANSDUCER
LOWER TRACES — "FLAT-SEAT" TRANSDUCER

FIG. (8) U.V. RECORDINGS OF OUTPUTS OF TWO BALANCED-DISC TRANSDUCERS SHOWING TIME LAG DUE TO OIL ON FLAT SEATS.



(a) THIN DISC
(b) THICK DISC

FIG. 7. PROBABLE PRESSURE DISTRIBUTIONS AND DEFLECTED FORMS FOR THIN AND THICK DISCS SUBJECTED TO STEP INPUTS.

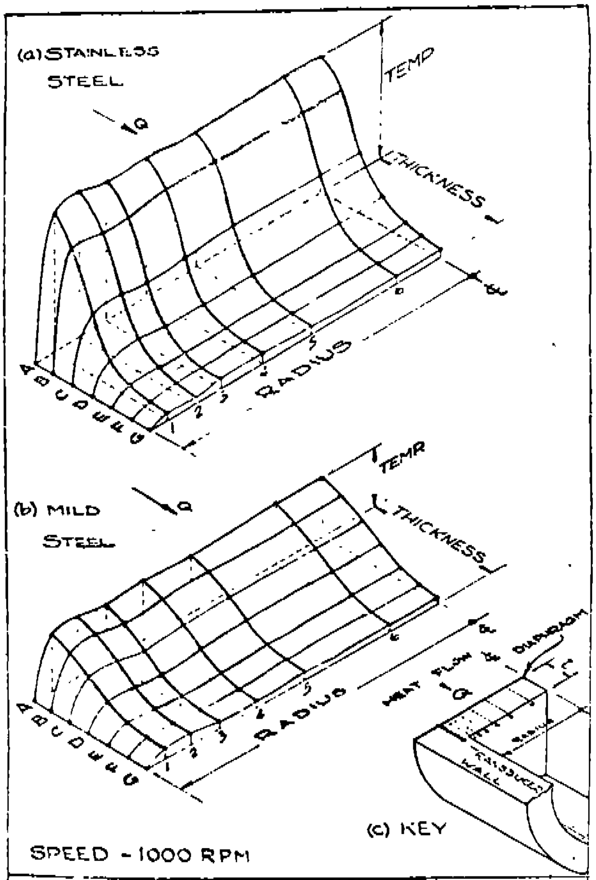


FIG. 9. TEMPERATURE DISTRIBUTION "SURFACES" AT TIME T. IN STAINLESS AND MILD STEEL DIAPHRAGMS FROM ELECTRICAL ANALOGUE.

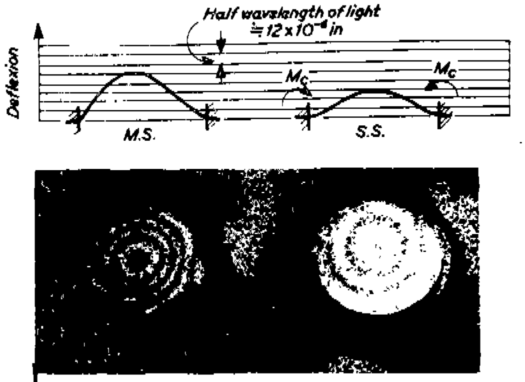
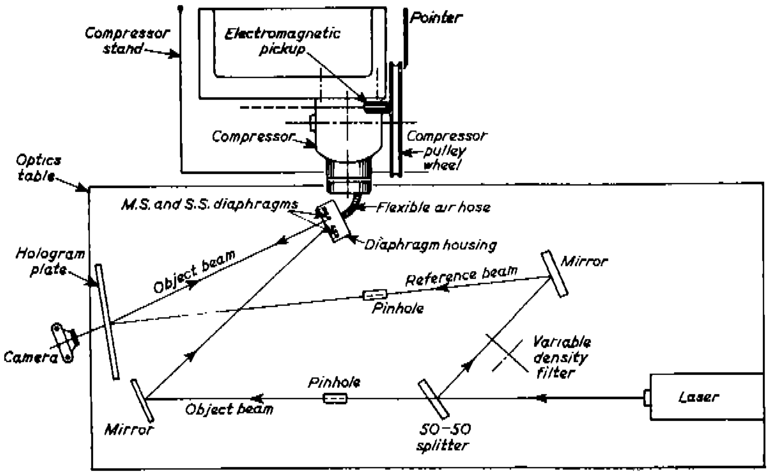


FIG. 11. ***"Fringes" recorded at 90° before b.d.c. for identical mild steel and stainless steel discs vibrating at 600 rev/min. The relative deflexions are shown***



Arrangement of air compressor and optics for the mild steel and stainless steel diaphragm holography

FIG. 10.