MEASUREMENT AND CONTROL OF IMPACT FINISHING PROCESSES

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ABSTRACT

A system of monitoring and regulating the shot peening intensity of a nozzle type peening machine has been designed. The overall aim is a machine capable of producing a required change in surface finish and strength by measuring both the kinetic energy of the shot peening material and the peening time. Two measuring systems are outlined and detailed results presented for the lower cost system.

KEYWORDS

Shot peening; correlation; capacitance transducer; computer based measurement; mass flow rate; Almen height; kinetic energy.

INTRODUCTION

Impact finishing or shot peening is a cold working process in which the metal surface is bombarded by small spherical particles usually steel or glass. Machined components are shot peened to improve their mechanical properties. Shot peening will increase the fatigue strength and also prevent corrosion cracking. Part of the kinetic energy of the stream of shot will cause plastic deformation in the metal surface thereby improving the mechanical properties (Maltby).

The intensity of shot peening depends on the kinetic energy and the time of exposure to the stream. Hence the peening intensity can be controlled by controlling the velocity and mass flow of the shot through the nozzle. However, the peening intensity is specified in terms of Almen arc height (Lunn, 1979; John, 1976). When a test strip (Almen Strip) of standard size and hardness is bolted to a block and peened on one side only, it will be forced into a two dimensional curve. The height of this curvature, the Almen arc height, is used as a measure of the peening intensity. If the Almen arc height is related to the kinetic energy of the stream, then the machine can be set and controlled for any specified Almen arc height intensity by measuring the velocity and mass flow.

CONTROL SCHEME

Two different measuring systems are outlined. The first uses a cross-correlator to measure the absolute mean particle velocity. In the second system the differential pressure developed across the solids feed valve is measured and related to particle feedrate and velocity using the correlator for calibration.

Two capacitance transducers and a cross-correlator are used to measure the mass flow and velocity as shown schematically in Fig. 1. The flow noise signals from the two transducers are similar except for a time delay. Hence if these signals are cross-correlated the transit time corresponding to the correlation peak will be equal to the time taken by the flow noise to travel from one electrode to the other. Knowing the distance between the two electrodes the velocity of the particle flow can be calculated (Ong, 1975; Beck, 1968). Further, the average noise signal from the transducer is a function of the concentration of the particles between the electrode. Since the concentration depends on the particle flow rate and velocity this average signal is a function of both mass flow and velocity. Expressing in mathematical form,

$$\text{Average flow noise, } x = f_1(m,v) \qquad \ldots (1)$$

where m is the mass flow and v the velocity. By measuring the particle flow per second for different feed rates and velocities we can calibrate the flowmeter reading in terms of velocity and mass flow. The kinetic energy of the stream can then be determined from the readings of the cross-correlator and the transducer.

The differential pressure between any two points in the system is again a function of velocity and mass flow. This can be expressed mathematically as

$$\text{Differential pressure, } y = f_2(v,m) \qquad \ldots (2)$$

Therefore by relating the differential pressure with velocity at different feed rates we can calculate the energy from the readings of the differential pressure transmitter and the transducer. This arrangement is shown schematically in Fig.2. The control scheme discussed in this paper uses the signals from the differential pressure transmitter and the transducer to control the stream energy. The differential pressure and the average flow noise signals are both functions of velocity and mass flow only. Hence when both mass flow and velocity are fixed, that is, when the stream energy is fixed, these two signals are also fixed. In other words, for a particular combination of these two signals the kinetic energy of the stream and hence the peening intensity is constant assuming other parameters do not vary. These other parameters are the impinging angle, time of exposure, the nozzle distance from the surface and the hardness of the work piece.

MEASUREMENT OF VELOCITY AND MASS FLOW

A schematic diagram of a compressed air type peening machine manufactured by Vacu-Blast Limited is shown in Fig. 3. When the compressed air is switched on the dump valve is closed and the pressure vessel is pressurised to the blast pressure (John, 1974). The abrasive is contained in the pressure vessel and is transferred by gravity to the blast stream through a feed valve. When blasting is stopped the pressure inside the vessel is exhausted opening the dump valve and permitting the abrasive to be transferred to the pressure chamber from the storage hopper.

Two Tealgate capacitance transducers are fitted in the blast hose to obtain the flow noise signals. The transducer consists of a capacitance electrode formed flush with the walls of the pipe so that there is no protrusion to obstruct the flow (Green, 1976). This electrode is made from hard wearing materials to withstand many hours of blasting with steel shot. The electrode is connected in parallel with an inductance to form a tuned circuit of a transistor oscillator. The frequency of oscillation varies with changes in the capacitance. These changes in frequency are converted to voltage changes by an f.m. demodulator. The high frequency component of this voltage is due to flow noise or flow turbulence, which is separated from the low frequency component using an a.c. amplifier. The amplified high frequency voltage signals are a function of the instantaneous solids concentration within the electrode field. The low frequency components are used to maintain the transducer at its optimum working point. Fig. 4.

A differential pressure transmitter is connected to measure the pressure drop across the solids feed valve. This transmitter provides an electrical output signal.

Steel shot of 280 micron diameter were used in the measurement. The peening machine was fitted with a 12 mm diameter blast hose and a 4.8 mm diameter nozzle. Readings were recorded at each differential pressure setting for a range of solids feed rates. The feed rate being adjusted by opening or closing the feed valve. The numbers shown in the graphs represent different settings of the feed valve - larger numbers representing lesser feed rate.

Fig. 5. shows the variations of the average flow noise signal (flowmeter reading) with variations in velocity and feed rate. This signal is a function of the particle concentration within the electrode sensing field. For a fixed feed rate when the velocity increases the concentration decreases. Hence the flowmeter reading decreases with increasing velocity. Fig. 6. represents the variation of mass flow with velocity for different feed valve settings. Fig. 7. is plotted from Figs. 5 and 6. and shows the changes in flowmeter reading with mass flow rate at constant velocities. Fig. 8. gives the relationship between velocity and differential pressure. The differential pressure increases with increasing velocity and feed rate. The relationship between flow noise and differential pressure for different valve settings is shown in Fig. 9.

The velocity shown in the above graphs is the measured particle velocity through the transducers. The actual velocity of the stream at the exit of the nozzle is about 7 times greater than this velocity due to the reduction in the cross-sectional area. This scaling factor depends on the air pressure and the feed valve setting. Further work is still required in this area.

Figs. 5 to 9. can be used for calculating the stream energy for any particular values of flow noise signal and velocity or differential pressure. These relationships are stored in the computer memory. The computer reads the signals from the transducer and cross-correlator or differential pressure transmitter and calculates the stream energy. A PET microcomputer was used for this purpose. Signals were fed into the computer using an A/D converter along with the necessary logic circuits.

MEASUREMENT OF ALMEN ARC HEIGHT

Almen arc height is measured using the Almen gauge. When a series of a specified type of Almen strips are peened under the same conditions at increasing exposure times and the arc height plotted, a saturation curve is obtained. The time necessary to produce saturation on a test strip is defined as the time required to achieve the specified arc height at which doubling the exposure time will not increase the arc height by more than 10%. The arc height peening intensity is always specified at the saturation value only (Fig. 10).

RELATIONSHIP BETWEEN STREAM ENERGY AND ALMEN ARC HEIGHT

To establish a relationship between the stream energy and the arc height peening intensity, a number of Almen strips were peened for different air pressure and feed valve settings. The signals from the differential pressure transmitter and the transducer were used to set the machine for a particular stream energy. Both these signals are functions of mass flow and velocity only. The stream energy corresponding to any particular combination of differential pressure and flow noise can be determined using the graphs obtained in section 3. Since the output of both the D.P. transmitter and the transducer are in milli amperes a current to voltage converter was used before connecting to the A/D converter. The conversion ratio for the transmitter was set to 100 m.V per p.s.i. and that for the transducer to 250 m.V per m.A. The input air pressure and the feed valve were simultaneously adjusted till the required combination of signals from the transmitter and the transducer were obtained. A number of Almen strips were peened with the same machine setting but different exposure times. Saturation curves were then plotted to determine the saturation arc height peening intensity and the corresponding exposure time. While peening the strips the nozzle was firmly held at a distance of 15 cm from the surface and the strip was moved to and fro to ensure a uniform coverage. Different machine settings were used so as to cover the normal working range of arc height intensity for the particular shot size and nozzle diameter used. Almen strip type A was used for all the measurements. The arc height and the saturation time for various combinations of differential pressure and flow noise signal are given in Table 1.

The flow noise signal can be increased by increasing the solids mass flow rate. However, to maintain the same differential pressure the velocity of the particles has to be decreased. Further, to increase the differential pressure keeping the flow noise fixed, the velocity has to be increased. Therefore, the stream energy and hence the arc height peening intensity decreases row wise and increases column wise as seen from Table 1.

		Flow noise in m. Volts						
		600	800	1000	1200	1400		
Differential Pressure in m Volts	250	50	45	40	40	38	Time	Saturation time in Secs. and Almen Arc height in inches
		0.0192	0.0155	0.0129	0.0118	0.0109	Arc height	
	300	55	50	45	43	40	Time	
		0.0206	0.0192	0.0156	0.0135	0.012	Arc height	
	350	55	45	40	35	30	Time	
		0.0247	0.0207	0.0174	0.016	0.0146	Arc height	

Table 1. Relationship between stream energy and Almen arc height intensity

A computer program in BASIC language was prepared to control the peening operation. The arc heights and saturation time corresponding to different machine settings were stored in the memory. When the required Almen height intensity is specified to the computer, the program will display the required machine setting and the exposure time using the stored information. The computer monitors the flow parameters and informs the operator when the stream is set correctly. Peening may then commence.

A few results are shown in Table 2. Almen strips were peened with the machine settings as specified by the computer. The corresponding arc heights obtained agree closely to the specified values.

Required arc height - inches	Machine Settings		Exposure time - secs.	Measured Arc height inches
	Diff. Pressure	Flow noise		
0.022	350	735	55	0.021
0.0175	350	993	45	0.0170
0.014	300	1152	45	0.0139

Table 2. Verification of machine settings for the required arc height intensity

CONCLUSION

Measurement of particle flow through a peening machine is discussed in this paper. The variations of mass flow, velocity and pressure drop for different input air pressures and feed valve settings are presented graphically. The Almen arc height and saturation time for different stream energies are also given. The peening machine can be set up easily to any specified Almen arc height intensity using the control scheme explained in this paper.

It is shown that signals from a single transducer and a differential pressure transmitter can be used to control the stream energy. Even though the velocity and mass flow are not directly measured in this scheme, these quantities can be calculated using the relationships explained in section 3. For a direct measurement of these quantities to control the stream energy, a cross-correlator and two transducers are required. Since a correlator costs much more than a differential pressure transmitter the control scheme explained in this paper will be less expensive for practical applications, however, it has a disadvantage in that it fails to account for wear in the blast hose of the machine. This wear effects the relationships between differential pressure, mass flow rate and velocity of the system.

Several variables are involved in the control of the peening process. If the effects of these parameters on peening intensity are established experimentally then this information can be stored in the computer. Further, the computer output can be used to set the air pressure and the feed valve for a specified peening intensity. The work of developing an automatic control scheme taking all the above parameters into account is proceeding.

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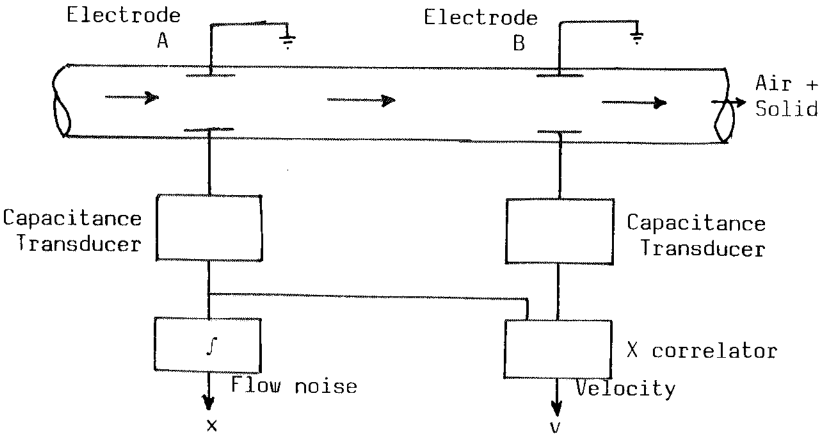

Fig. 1 Measuement of velocity and mass flow

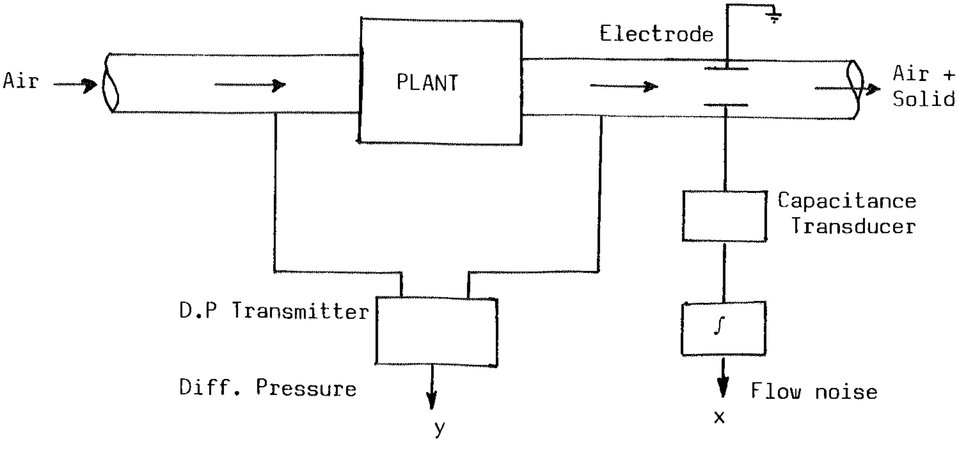

Fig. 2 Measurement of differential pressure and mass flow

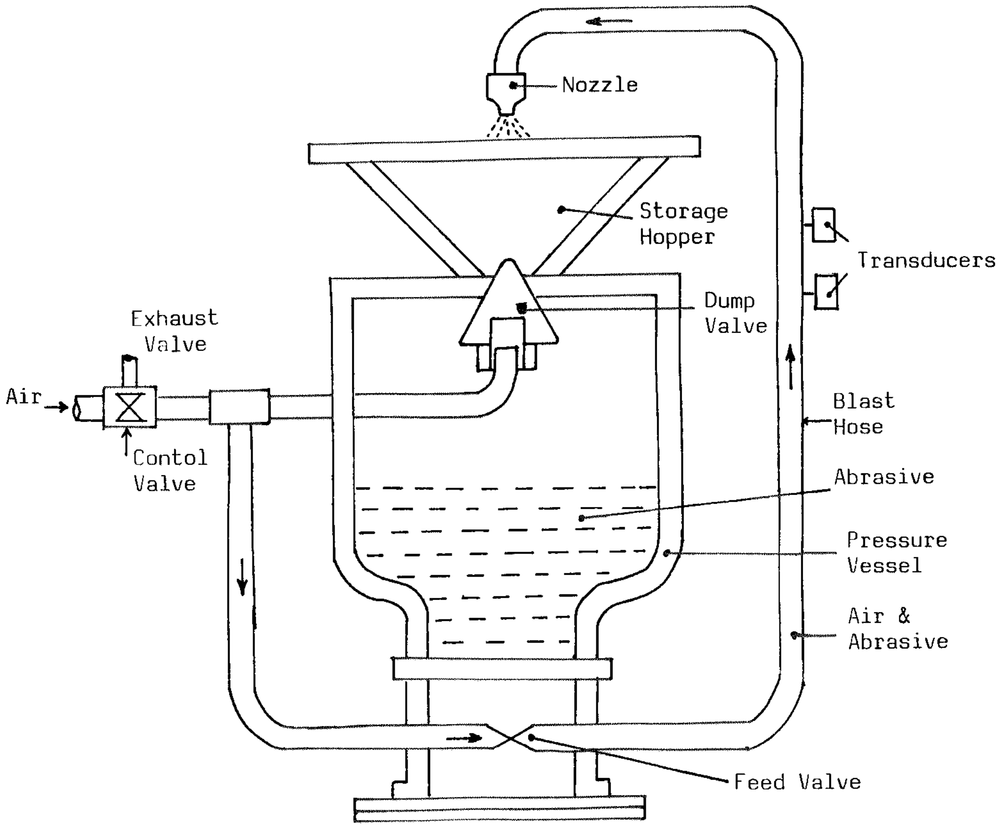

Fig. 3 Compressed Air Type Peening Machine

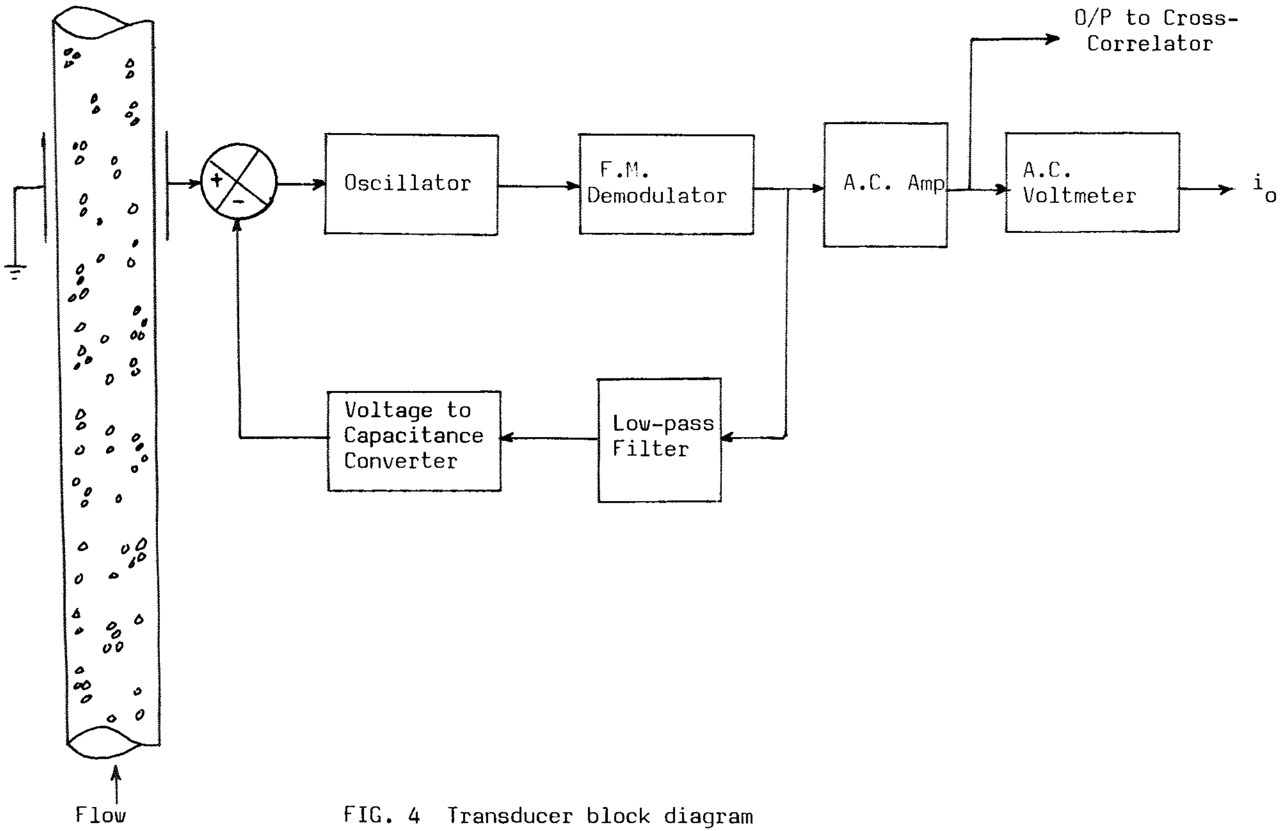

FIG. 4 Transducer block diagram

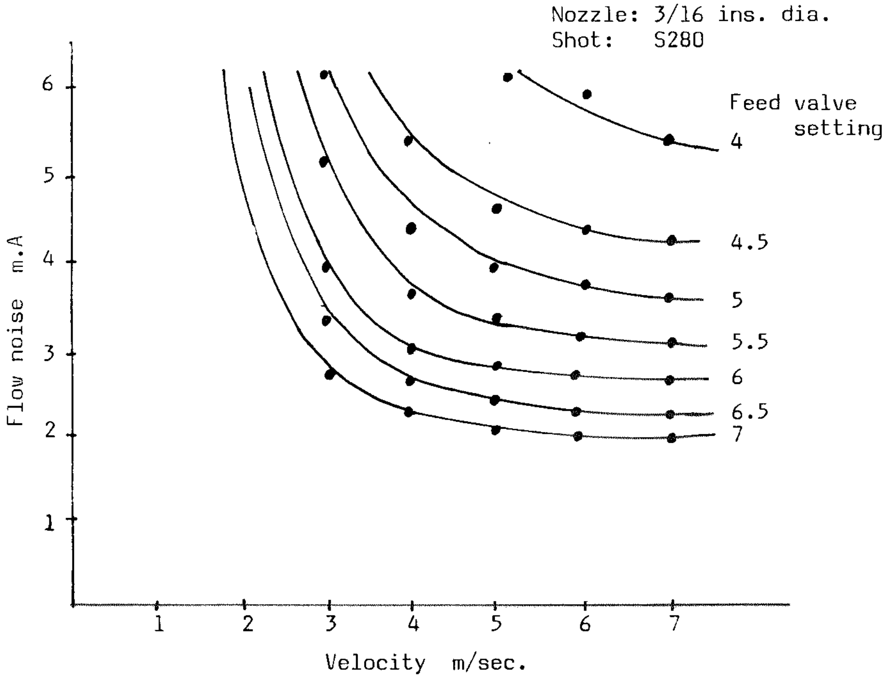

Fig. 5 Relationship between flow noise and velocity at different feed valve settings

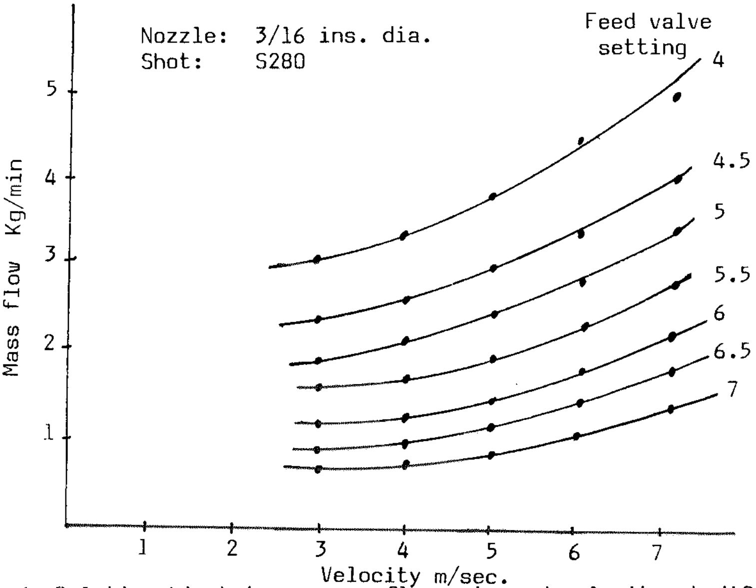

Fig. 6 Relationship between mass flow rate and velocity at different feed valve settings

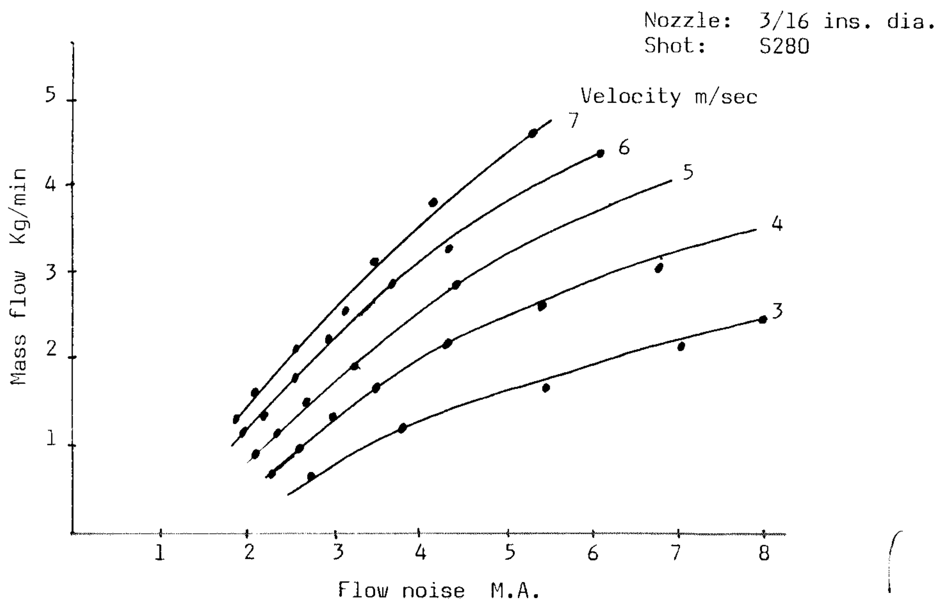

Fig. 7 Relationship between mass flow rate and flow noise at constant velocities

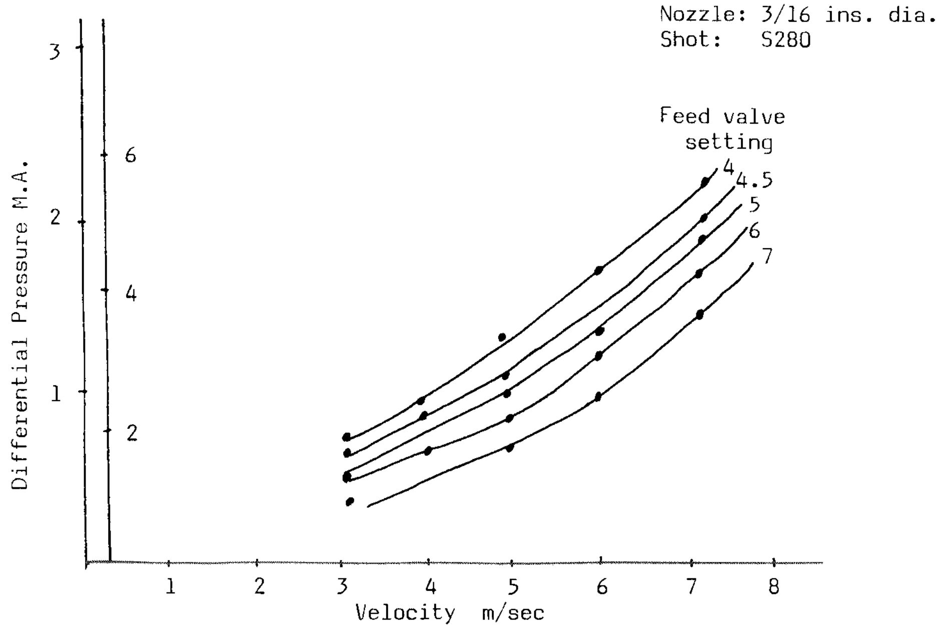

Fig. 8 Relationship between differential pressure and velocity at different feed valve settings

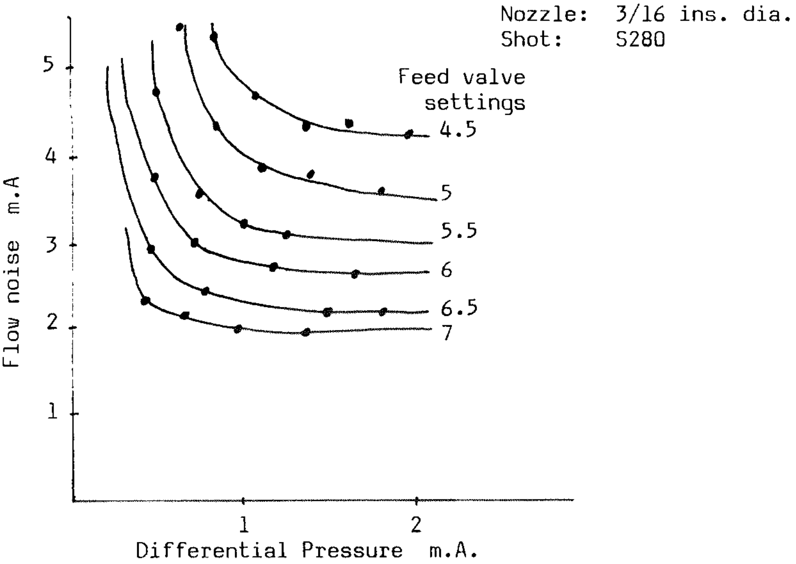

Fig. 9 Relationship between flow noise and differential pressure at different feed valve settings

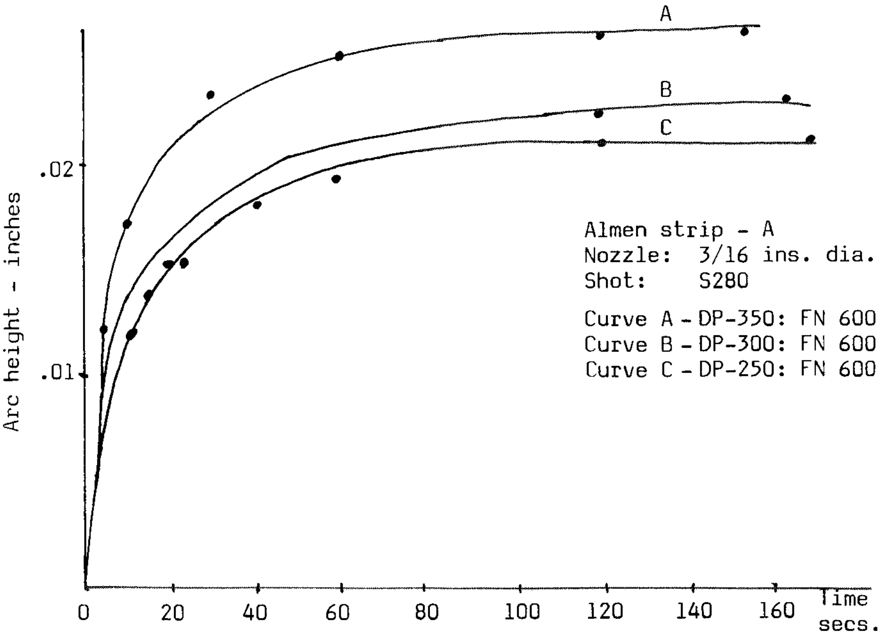

Fig. 10 Saturation curves showing variation in Almen Arc height with time