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A METHOD OF MEASURING THE IMPACT VELOCITY OF FLAPPER VALVES

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ABSTRACT

A new device has been developed by which the impact velocities of flapper valves can be measured. It is based on a capacitive principle, the valve and the seat providing parts of a capacitor. The output signal is proportional to the velocity.

In addition, it will be shown that impacts can be recorded continuously using a minicomputer. This arrangement offers a means of determining the distribution of impact velocities. This distribution has a shape which resembles the distribution of impact angles.

INTRODUCTION

When analysing an impact fatigue test it is of crucial importance to, by some means, measure the impact "intensity". For instance, the assessment of an S-N curve requires the determination of the impact stress or some alternative parameter which may be <u>related</u> to the stress.

In a previous report, Svenzon (1) described the method of measuring impact intensity by means of an accelerometer. It was concluded that the signal was proportional to the energy. Svenzon (2) showed in his thesis that the accelerometer signal could be related to the impact velocity, as determined by high-speed photography. However, it was frequently observed that the tip of the flapper valve was blurred, showing that the impact velocity was too high to be recorded accurately with the exposure time used. In addition, this technique is extremely time consuming and is unsuitable for a continuous recording of velocity.

The authors believe that the velocity is a more adequate measure of impact intensity than the accelerometer signal, since the velocity signal - in contrast to the accelerometer signal - is independent of valve thickness. In addition, the velocity signal has proved advantageous from the point that it may be correlated to the induced stresses (see Ref. 3). Therefore, attempts have been made in the present investigation to develop an electronic device, by which velocity signals may be collected more easily than from high-speed photography. The first version built relied upon an inductive principle, but was considered too slow (maximum carrier frequency 2 MHz corresponding to a resolution limit of 10 m/s). A capacitive device employing a carrier frequency (16 kHz) was also discussed because of its ability to measure static distances. This property facilitates a calibration of the velocity signal but has the disadvantage of being far too slow. It is estimated that the capacitive principle would require a carrier frequency of 5 MHz for the present purpose. A device using so high a frequency is not available.

The final version is a slightly different capacitive device, which is faster than the above mentioned types. It will be shown in this paper that the method employed at Sandvik in our SIFT is sufficiently fast for the purpose of measuring impact velocities. The calibration of the velocity signal, which requires the use of high-speed photography, will be attempted in the near future.

It has previously been demonstrated that a large portion of impacts are skew, an example of which is presented in Fig. 7, Ref. 1. It is suggested in the same reference that impacts if high skewness give rise to whip-lash effects and consequently high impact velocities. The present investigation attempts to correlate the distribution of angles to an experimental recording of velocity distribution. It will be shown that great similarities prevail.

EXPERIMENTAL

Velocity measurement

The method of measuring impact velocities which will be explained here, relies on a principle whereby changes in capacitance is recorded (see Fig. 1). Within the seat there are two separate segments which, in conjunction with the flapper valve, constitute two capacitors connected in series. The closest distance between the segments and the valve is 1.0 mm, i.e. when the valve tongue lies flat on the seat. This distance has been chosen comparatively large to make the change in capacitance approximately linearly proportional to the valve distance change in the final stage of approach to the seat. Disregarding the capacitance between the segments themselves and other stray capacitances and assuming an inverse relation between total capacitance (C) and distance (x), we may write

$$C \sim \frac{1}{x}$$

Logarithmic differentiation of both sides of the equality yields

$$\frac{\delta C}{C_o} - \frac{\delta x}{x_o}$$

where C_o and x_o correspond to contact between the flapper valve and the seat.

The capacitor is charged through a resistor. Since the resistance is large (200 MΩ) the associated time constant becomes large (~5 ms), hence also the charging time. This implies that the charge in the capacitor is virtually constant during the final stage of impact, and the time derivative of the charge vanishes. As a result, the change in capacitance due to the change in flapper valve position may to a very good approximation be related to the corresponding change in voltage.

Differentiating the voltage across the capacitor with respect to time yields an output signal which is proportional to - and thus an indirect measure of - the impact velocity. However, there is no simple way of determining the constant of proportionality. This, for instance, would be possible for capacitive methods using a carrier frequency, since then static distances could be determined. On the other hand, these methods are not sufficiently fast to cope with the rapid changes occurring in the present application, where the velocity, as estimated by high-speed photography, may be of the order 10 m/s.

Recording of velocity distribution

An electronic device based on a minicomputer has been developed at Sandvik for the purpose of continuously recording the impacts. This device enables the velocity and accelerometer distributions to be determined simultaneously. It is also possible to alter the set size so that only the maximum value of n consecutive events, where n = 1, ...999, may be recorded. The purpose of this is to reduce the frequency of information so that a chart recorder may be employed to collect data. In addition, this gives an opportunity of recording only impacts of high intensity, which are considered to be most harmful.

The results shown in the present paper were obtained by collecting the output signals with a tape recorder and feeding them into a computer. The histograms were then obtained from the graphical terminal.

RESULTS

A large number of velocity distributions have been obtained. The histograms shown in the present paper have been selected for the purpose of illustrating some general features of recorded velocity distributions. A comparison with the corresponding distribution of the accelerometer signal will also be made.

A typical example of a velocity distribution obtained when recording each of 2000 consecutive impacts is presented in Fig. 3. This histogram reflects the general observation that there is a rather long "tail" towards high velocities when every impact is recorded. This skewness may be quantified using the mathematical expression for skewness which is

$$E\{(\xi - \mu)^3\}/\sigma^3$$

where μ is the mean value of the stochastic variable ξ and σ^2 is the variance. In the example given above the skewness was calculated to 1.07 (see Table 1).

When the impact intensity is increased, the tail often becomes more pronounced and the associated skewness increases. This effect may be observed by comparing Fig. 3 with Fig. 4, where the velocity is increased by approximately 50 %. It may be observed that the skewness increases from 1.07 to 1.57, whereas the general shape of the distribution remains unaltered.

Fig. 5 is the symmetric distribution which is obtained when only the maxima of every 200 impacts are recorded. However, the number of recorded impacts is the same, 2000, and the impact level corresponds to that used in Fig. 3. It was observed in a large number of cases that the skewness decreased (both velocity and accelerometer signal) when the set size increased.

As is illustrated in Fig. 6, the distribution of the accelerometer signal very much resembles the corresponding velocity signal (cf. Fig. 4). In both cases we observe a tail towards higher values, although the skewness is somewhat less in Fig. 6 than in the examples shown in Fig. 3 and Fig. 4.

DISCUSSION

It has been demonstrated in the present paper that impact velocities may be recorded using capacitive electronics. Since the output signal is proportional to the impact velocity, a calibration is in principle possible by means of an independent source, e.g. a high-speed camera. However, the camera used by Svenzon (2) was not sufficiently fast to record whip-lashes. In Svenzon's investigation the exposure time was estimated to ~10 μs, a time interval which corresponds to a tip movement of ~100 μm. The calibration, which was not performed in the present work, therefore requires an exposure time which is shorter than 10 μs. We estimate that 1 μs exposure time, corresponding to a 10 μm tip movement, would be sufficient. High-speed cameras having an exposure time of 1 μs are now available. Therefore, this calibration is in principle possible to perform.

It is necessary to analyse whip-lashes, since it is believed that these are most dangerous to the material. The capacitive technique described here offers one possible method. However, an inevitable consequence of the capacitor design is that the signal is integrated over a relatively large area of the valve. Therefore, the movement of any selected part of the valve tongue can not - in contrast to photographic techniques - be recorded. In particular, the velocity of the valve tip will probably be underestimated. This is unfortunate since virtually all fractures initiate in this region.

The technique of measuring velocities described here has the advantage that it enables us to present the velocity distribution. It may be observed that there is a considerable scatter of impact velocities. The likely explanation to this behaviour is the spread in impact angle, which has been experimentally verified by Svenzon (2).

When every impact is collected the associated distribution exhibits a positive skewness. The long "tail" towards higher intensities is attributed to the whip-lash impacts or - equivalently - impacts of high obliquity. It is expected that this effect is enhanced at higher impact levels when the amplitude of the resonance vibrations increases. The validity of this statement can be noted by comparing Fig. 3 and Fig. 4.

When the maxima of 200 consecutive impacts are recorded, the corresponding distribution tends to be approximately symmetric. This has been interpreted as an experimental verification that the corresponding stochastic variable becomes symmetrically distributed when the set size is chosen sufficiently large.

It is possible that there exists a threshold velocity, such that only those impacts which exceed this threshold value would cause damage to the material. If this is true, it implies that, when choosing the set size properly, it ought to be possible to record only those impacts which contribute to failure.

CONCLUSIONS

1. It has been experimentally shown that individual impacts may be analysed with respect to velocity by a capacitive technique developed at Sandvik.
2. Furthermore, individual impacts may be recorded to assess the distribution of impact velocities.
3. The velocity distribution assumes a shape resembling the distribution of angles obtained by Svenzon (2). The large scatter of velocities is attributed to a corresponding variation in impact angle.

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3. L. Nilsson, J-O Nilsson. Stress analysis of impact fatigue of valve steel using the FEM. to be published.

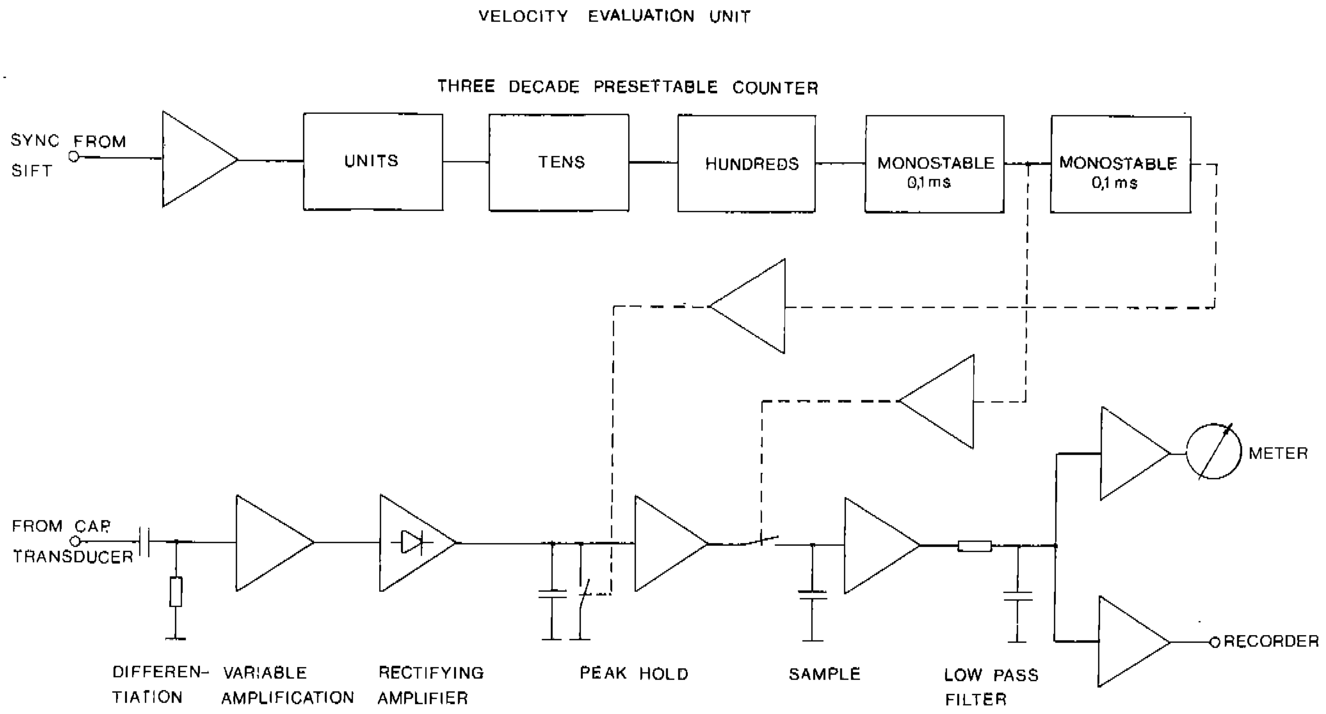

Figure 1
Impact velocity evaluation unit. Block diagram.

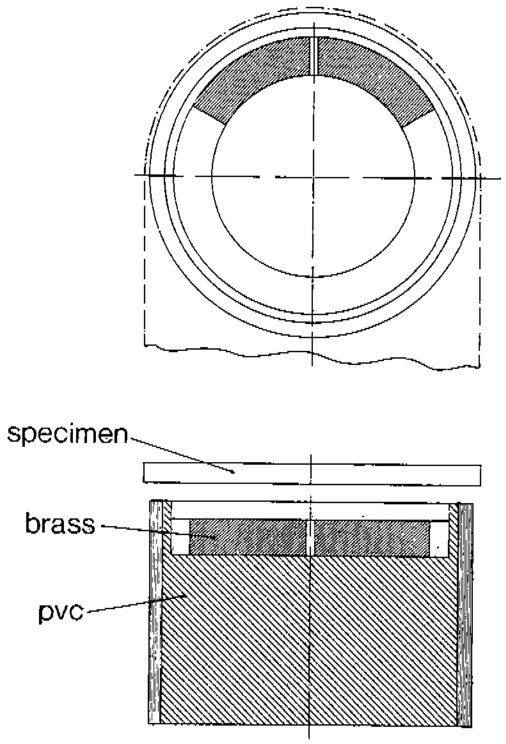

Figure 2
Capacitive transducer. The two brass parts, mounted in the cylindrical seat, and the specimen comprise two capacitors in series.

∼ 2 x

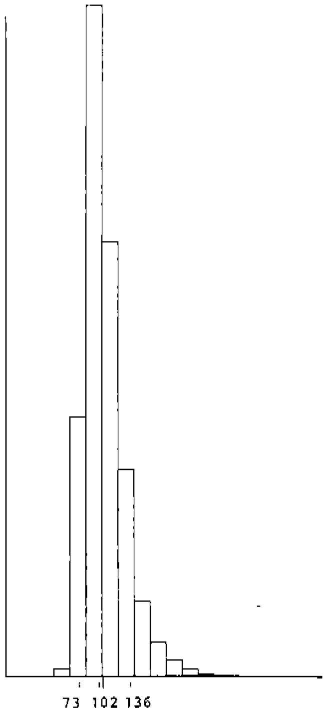

Figure 3
Low velocity distribution.
Each impact recorded.

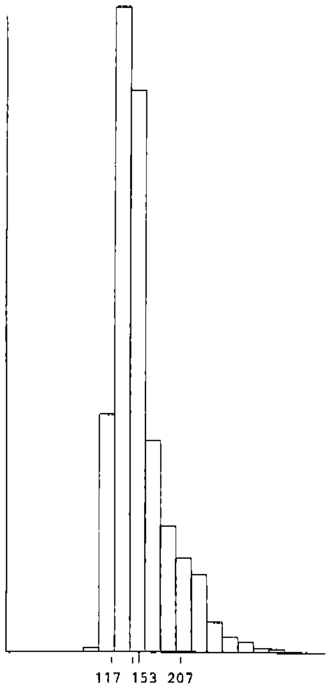

Figure 4
Medium velocity distribution.
Each impact recorded.

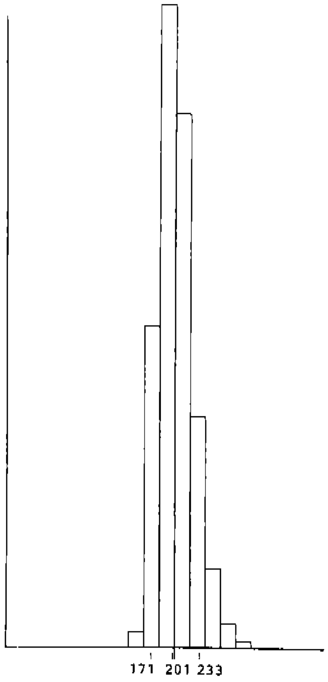

Figure 5
Low velocity distribution, same as figure 3.
Max. of 200 consecutive impacts recorded.

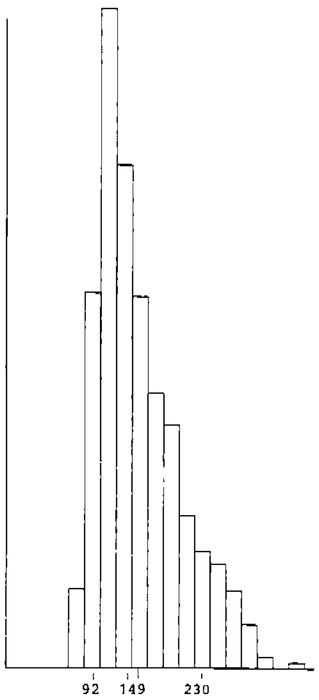

Figure 6
Distribution of accelerometer signal.
Level corresponds to figure 4.
Each impact recorded.

The numbers below the frequency histograms refer to 10 %, mean and 90 % value respectively. Scale factors for velocity and for accelerometer signal are arbitrarily chosen.

TABLE 1

Figure	3	4	5	6
Mean value	102	153	201	149
Median	98	144	198	136
Skewness	1.09	1.57	0.04	0.75