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Probe Velocity Transducer

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PROBE VELOCITY TRANSDUCER

by

V. S. Starkovich, B. E. Todd, E. L. Stephani, and E. V. Hawkins

ABSTRACT

A simple velocity transducer for determining x-ray produced blowoff impulse is described. The device does not require active calibration and can operate over a wide dynamic range in severe nuclear radiation environments.

I. INTRODUCTION

One of the many longstanding problems associated with existing impulse gauges used in the measurement of x-ray produced blowoff impulse has been the necessity for conducting active laboratory and field calibration measurements. The most desirable method is one which would eliminate the need for active calibration measurements, minimize field installation time, and provide for immediate data reduction, while eliminating costly data digitization and curve fitting procedures. The system must also operate reliably in severe nuclear radiation environments and be compatible with a variety of relatively inexpensive signal recording techniques.

A simple velocity transducer has been developed which does not require active calibration and is capable of providing accurate impulse measurements between 2×10^3 and 4×10^6 dyne-sec (~ 100 to 200,000 dyne-sec/cm² for commonly used areas and masses). The capacity for making measurements over such a wide range of impulse/unit area without active gauge calibration is both unique and extremely useful, because field installation time is reduced and reduction of the calibration data and construction of associated hardware fixtures are eliminated. The characteristic shape and relatively low frequency of the output signal simplify reduction of the shot data and permit the use of shielded twisted pair cable for signal transmission to distant recording facilities.

II. THEORY OF OPERATION

Figure 1 shows a schematic of the velocity transducer. The main components of the gauge are a metal rod into which equally spaced rings have been machined, and a Bently-Nevada inductive proximity probe* to sense the passing of each ring. The inductive probe used in these experiments consists of a flat coil of copper wire located at the end of a small ceramic cylinder filled with epoxy. The 0.125-in.-diam probe can operate over the temperature range of -30° to $+400^\circ\text{F}$. The coil itself is protected by 0.010 in. of epoxy and is not visible to the naked eye.

Figure 2 is a block diagram of the electronics used in a typical transducer system in the field. In addition to the probe coil, an oscillator-demodulator circuit, power supply, and line driver are used along with signal recording equipment. A

Fig. 1. Probe velocity transducer (PVT).

*Bently probe model 322-L6 was used for these measurements.

Fig. 2. Block diagram of electronics for a typical field transducer system.

-15-Vdc signal from the power supply is applied at the oscillator-demodulator (proximator) input terminals. The proximator converts this voltage into an rf (~ 1 MHz) signal, which is applied to the probe through a coaxial cable. The probe coil radiates this signal into the surrounding area as a magnetic field. If there is no conductive material to intercept the magnetic field (gap in the rod) there is no loss of rf signal. When a conductive surface approaches the probe tip, eddy currents are generated on the surface of the material and power is absorbed. The proximator senses the change in the amplitude of the rf envelope and provides a dc signal output corresponding to the negative peaks of the envelope.

The dc voltage "spike" generated by the passing ring (see Fig. 3) can be directly measured or amplified and sent over twisted pair or coaxial cable to distant recording facilities. Because the ring spacing and mass of the moving assembly as well as the exposed sample area are known, one need only record the periodic change in the dc signal level as a function of time to determine the impulse/unit area imparted to the sample.

The range, linearity, and output of the probe are determined by the rod-ring spacing, usually ~ 0.015 in., and the conductivity of the rings (copper, aluminum, and brass produce the largest signals). The portion of the system between the probe and proximator contains a tuned 1-MHz circuit, and the length of the 50-ohm extension cable must be matched to the length of the 95-ohm probe lead as well as to the probe itself. If recommended cable lengths are employed, matching can be easily accomplished by an adjustment in gain. Although rod velocities are generally greater than 1000 cm/sec and ring spacings are on the order of 0.5 cm, the standard proximator-probe frequency response of 10 kHz is more than sufficient for this application.

Eddy current probes are typically linear over the majority of their operating range, but non-linear effects are of no concern here. Only the location in time of each dc voltage peak is needed to determine the rod velocity. This feature contributes to good signal readability under severe nuclear radiation and cable noise conditions. An effort is under way to redesign the proximator circuit to accommodate a longer extension cable so that the oscillator-demodulator circuit can be further removed from the radiation environment.

Figure 4 is a view of the assembled and dis-assembled gauge. The purpose of the aluminum honey-comb in Fig. 4 is to provide a backup passive measurement of the impulse imparted to the cup.

III. RESULTS OF DYNAMIC TESTS

As part of the development process, the probe velocity transducer (PVT) was dynamically tested over the impulse range of 1800 dyne-sec to approximately 1×10^6 dyne-sec. Air rifles and sheet explosives¹ were used to produce impulse in these tests. Experience with other types of impulse

Fig. 3. Schematics of signals produced by (a) proximator, (b) line driver.

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Fig. 4. Assembled (top) and disassembled gauge.

gauges has shown that such tests, particularly those at high impulse, are extremely useful for examining possible structural failures as well as for improving signal recording techniques.

Representative signals recorded during these tests are presented in Fig. 5, with actual impulse results presented in Table I. For the experiments conducted with the air rifles, a calibrated chronograph was used to determine the BB or pellet velocity. Uncertainties in these data range between 1/2 and 2% and are due to pellet mass variations and uncertainties in the velocity measurement. The primary purpose of these relatively low impulse measurements was to examine frictional effects and to determine a practical low-impulse threshold of the transducer. Although impulse measurements below

those included in Table I were conducted, scatter in the data indicated that the gauge was not suitable for measurements in this region to an accuracy of better than 30%.

The primary purpose of the tests using sheet explosive was to examine the upper impulse threshold of the gauge and determine at what rod velocities phenomena such as rod resonance, ball bearing response, and friction would begin to play a significant role.

No significant friction effects (scratching) from the steel ball bushings were observed for aluminum rod velocities up to 1500 cm/sec. Above this velocity, visible scratching did occur, but it was not noticeable in the data analysis. A study is being made of other types of bearings (nylon)

Signal 2. 2 msec/cm 2V/cm

Signal 5. 0.2 msec/cm 2V/cm

Signal 43. 20 msec/cm 2V/cm

Signal 68. 10 msec/cm 2V/cm

Fig. 5. Representative signals.

TABLE I
HIGH EXPLOSIVE DYNAMIC TESTS

Mode	Signal No.	I gauge (10^3 dyne-sec)
HE	2	219.7 $\pm$ 7.8
HE	3	256.6 $\pm$ 5.5
HE	4	948.0 $\pm$ 36.5
HE	5	869.7 $\pm$ 21.0

AIR RIFLE DYNAMIC TESTS

Mode	Signal No.	I _{BB} (dyne-sec)	I gauge (dyne-sec)	I _{BB} -I gauge (dyne-sec)
BB	42	1,930 $\pm$ 10.0	1,850 $\pm$ 140	80 $\pm$ 140
BB	43	3,220 $\pm$ 15	2,970 $\pm$ 70	250 $\pm$ 70
BB	44	3,330 $\pm$ 15	2,785 $\pm$ 60	545 $\pm$ 60
BB	45	4,845 $\pm$ 25	4,890 $\pm$ 95	-45 $\pm$ 100
BB	46	4,830 $\pm$ 25	4,400 $\pm$ 80	430 $\pm$ 85
BB	47	6,940 $\pm$ 35	6,255 $\pm$ 150	685 $\pm$ 155
BB	50	7,060 $\pm$ 35	6,600 $\pm$ 35	460 $\pm$ 170
BB	51	9,040 $\pm$ 45	8,040 $\pm$ 120	1,000 $\pm$ 130
BB	52	8,395 $\pm$ 40	7,105 $\pm$ 95	1,290 $\pm$ 105
BB	53	9,860 $\pm$ 50	9,475 $\pm$ 170	385 $\pm$ 175
BB	54	10,250 $\pm$ 50	8,405 $\pm$ 130	1,845 $\pm$ 140
BB	55	10,620 $\pm$ 55	8,800 $\pm$ 145	1,820 $\pm$ 150
BB	56	10,875 $\pm$ 55	9,870 $\pm$ 355	1,095 $\pm$ 360
Pellet	57	15,000 $\pm$ 310	15,225 $\pm$ 300	-225 $\pm$ 430
Pellet	58	15,235 $\pm$ 310	15,415 $\pm$ 300	-180 $\pm$ 430
Pellet	59	17,755 $\pm$ 365	17,940 $\pm$ 410	-185 $\pm$ 550
Pellet	60	20,040 $\pm$ 410	19,950 $\pm$ 500	90 $\pm$ 650
Pellet	61	19,920 $\pm$ 410	19,655 $\pm$ 480	265 $\pm$ 630
Pellet	62	22,705 $\pm$ 480	23,145 $\pm$ 625	-440 $\pm$ 790
Pellet	63	22,945 $\pm$ 470	23,290 $\pm$ 630	-345 $\pm$ 785
Pellet	64	23,300 $\pm$ 480	22,920 $\pm$ 600	380 $\pm$ 770
Pellet	65	21,820 $\pm$ 450	22,440 $\pm$ 575	-620 $\pm$ 730
Pellet	66	27,890 $\pm$ 140	27,770 $\pm$ 870	120 $\pm$ 880
Pellet	67	32,985 $\pm$ 165	32,195 $\pm$ 1150	790 $\pm$ 1160
Pellet	68	30,420 $\pm$ 150	30,630 $\pm$ 1030	-210 $\pm$ 1030

which might be more suitable for use at high rod velocities. Table II presents the raw data as digitized (arbitrary units) from the signals shown in Fig. 5. Oscilloscope time calibration is included in the results. The increasing numbers as a function of time indicate a decrease in rod velocity from frictional and air drag effects. The variations in signal level seen in Signals 2 and 5 are due to rod resonance. The unusually large distance to the first peak in Signals 2 and 5 is also thought to be shock related, and an effort is being made to shock-mount the probe for future measurements above 10^5 dyne-sec.

IV. NUCLEAR ENVIRONMENT TESTS

The one obvious disadvantage of the PVT gauge is the requirement that the probe and proximator be located underground. These components, however, have had a long history of success at the Nevada Test Site and evidence suggests that the inductive probe can withstand total neutron fluxes of up to 10^{16} n/cm² with recovery times being generally less than 1 msec. In-house measurements indicate that the proximator and microdot cable can withstand

TABLE II

DIGITIZED SIGNAL PEAK SPACINGS

Signal 2 (2.1×10^5 dyne-sec)	Signal 5 (8.7×10^5 dyne-sec)	Signal 43 (3.2×10^3 dyne-sec)	Signal 68 (3×10^4 dyne-sec)
58 $\pm$ 1	95 $\pm$ 1	88 $\pm$ 1	30 $\pm$ 1
56 $\pm$ 1	81 $\pm$ 1	92 $\pm$ 1	30 $\pm$ 1
57 $\pm$ 1	81 $\pm$ 1	102 $\pm$ 1	29 $\pm$ 1
56 $\pm$ 1	77 $\pm$ 1	106 $\pm$ 1	31 $\pm$ 1
59 $\pm$ 1	82 $\pm$ 1	117 $\pm$ 1	31 $\pm$ 1
59 $\pm$ 1	83 $\pm$ 1	127 $\pm$ 1	32 $\pm$ 1
57 $\pm$ 1	83 $\pm$ 1	134 $\pm$ 1	31 $\pm$ 1
59 $\pm$ 1	83 $\pm$ 1	150 $\pm$ 1	31 $\pm$ 1
58 $\pm$ 1	85 $\pm$ 1	159 $\pm$ 1	35 $\pm$ 1
58 $\pm$ 1	86 $\pm$ 1		31 $\pm$ 1
60 $\pm$ 1	88 $\pm$ 1		31 $\pm$ 1
60 $\pm$ 1	86 $\pm$ 1		34 $\pm$ 1
59 $\pm$ 1	86 $\pm$ 1		33 $\pm$ 1
59 $\pm$ 1	89 $\pm$ 1		35 $\pm$ 1
61 $\pm$ 1			34 $\pm$ 1
			33 $\pm$ 1
			35 $\pm$ 1
			36 $\pm$ 1

total neutron doses in excess of 10^{13} n/cm², with radiation-induced signal no larger than 3.5 v (~25% initial amplitude) at doses above 4×10^{12} n/cm². Figure 6 shows two signals recorded in a recent underground test. An FR-1400 tape deck with a frequency response of 20 kHz FM was used. Because an important consideration in data recording is the relative times of change in the dc signal level as each ring passes the probe, non-linear effects produced by radiation of the probe and electronics are not of primary concern.

V. SUMMARY

Two gauges currently in use for active

measurement of x-ray blowoff impulse at the Nevada Test Site are the Displacement Transducer (DT) and the Linear Velocity Transducer (LVT). In the DT gauge a ferromagnetic-tipped rod attached to the sample cup is driven along the common axis of two adjacent transformer windings, the primary of which is excited by a 15-V peak-peak 100-kHz signal. Because the change in the signal amplitude from the secondary winding is a function of rod displacement, an active calibration is necessary. In the LVT gauge the sample cup is attached to a magnetic material which is driven through a pick-up coil. The LVT gauge must also be actively calibrated, because the output current is proportional to the

0.5 V/cm, 5 msec/cm

0.5 V/cm, 3 msec/cm

Fig. 6. PVT signals from a recent underground test.

TABLE III
COMPARISON OF PVT, DT, AND LVT GAUGES

PVT	DT	LVT
1. Fast data reduction from digitized voltage peak locations.	Data reduction involves computer fitting procedures and streak film digitization.	Signal reducing procedures require integration and differentiation of output signal.
2. No active calibration necessary.	Calibration procedure requires hard film reading, computer handling of data and special hardware fixtures.	Active calibration requires dynamic tests.
3. All active elements commercially available.	Coils are hand wound, while oscillators are purchased.	All active elements commercially available.
4. Impulse range 100-200,000 $\frac{\text{dyne-sec}}{\text{cm}^2}$	Impulse range 100-300,000 $\frac{\text{dyne-sec}}{\text{cm}^2}$	Impulse range 100-300,000 $\frac{\text{dyne-sec}}{\text{cm}^2}$
5. Signal (~ 1 kHz) can be transmitted over shielded twisted pair cable.	Signal (~ 100 kHz) requires coaxial cable.	Signal can be transmitted over shielded twisted pair cable.
6. Reliability of proximator and probe proven at NTS.	Proven reliability. Insensitive to cable noise.	Proven reliability. Insensitive to cable noise.
7. Signal can be multiplexed by employing voltage control oscillators.	Signal can be multiplexed by an active adder circuit.	Signal can be multiplexed by employing voltage control oscillators.
8. Dry run signal not representative of shot signal.	Dry run signal is fully representative of shot signal.	Dry run signal not representative of shot signal.
9. Requires active electronics downhole.	Requires active electronics downhole.	Does not require active electronics downhole.

velocity of the magnetic material. Table III summarizes the features of the PVT, DT, and LVT gauges.

As indicated in Table III, signals from the PVT gauge can be multiplexed by using voltage control oscillators with adequate frequency response. In this configuration coaxial cable would have to be used for signal transmission to the recording station.

In conclusion, a simple velocity transducer for measuring x-ray produced blowoff impulse has been developed. The transducer produces a continuous time resolved output that provides an internal velocity determination. In addition, the gauge can operate over a wide dynamic range in severe nuclear radiation environments, does not require active calibration either in the laboratory or the field and produces a signal which can be easily inter-

preted. In the non-multiplexed configuration, relatively inexpensive shielded twisted pair cable can be used for signal transmission to distant recording facilities.

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