A DIGITAL INSTRUMENTATION SYSTEM FOR AUTOMOTIVE IMPACT TESTS[1]

A. S. HU, S. P. BEAN and J. J. MAURE
Physical Science Laboratory
New Mexico State University

Summary. Automotive impact tests require the transmission oflarge amount of measurement data through drag cables. The traditional practice of using FM technique is tedious and expensive. An on-board PCM system which accepts 112 analog inputs and 91 bi-level inputs has been used successfully at the Daisy Impact Sled Test Track located at the Holloman AFB. This system utilizes a two-conductor pair drag cable. It can also be telemetered by pulse modulating a radio frequency carrier.

Introduction. Instrumented human subjects or anthropomorphic test dummies are widely used in biomechanics research in order to obtain knowledge on the mechanisms of human impact injury and on specifying injury threshold. This knowledge is the design basis for vehicle safety equipment and for specifying the limiting forces and accelerations which may be imposed on a human subject during an impact required by the Federal Motor Vehicle Safety Specifications.

Previously reported impact test instrumentation systems [1], [2] used analog data acquisition and recording techniques, where a digitizer was used immediately prior to feeding the digital computer. This arrangement required a large amount of manual labor to calibrate, adjust, and record the large number of data channels. An on-board PCM system which accepts 112 analog inputs and 91 bi-level inputs has been used successfully at the Daisy Impact Sled Test Facility located at the Holloman AFB. The purpose of this paper is to present this PCM system which is used to instrument the entire impact test. This includes the instrumentation of the test subject, sled, seats, belts, etc.

Sled Impact System. The Daisy Sled, a decelerating impact test facility, consists of two tubular rails separated by a distance of 5 feet and extending for a length of 200 feet. The sled is supported on each rail by two bronze slippers. Sled propulsion is provided by a 40-ft pneumatic piston which accelerates the sled from one end of the track.

---

[1] This work was supported by the Department of Transportation, National Highway Traffic Safety Administration under Contract DOT-HS-5-01201. However, the opinions, findings, and conclusions stated herein are those of the author and do not necessarily represent the position of the Department of Transportation.

A water cylinder brake located at the other end of the track provides the deceleration impact. The stopping distance is adjustable up to 48 inches and the deceleration impact profile is pre-programmed by selecting proper orifice sizes. Figure 1 shows the sled with an anthropomorphic test dummy as test subject.

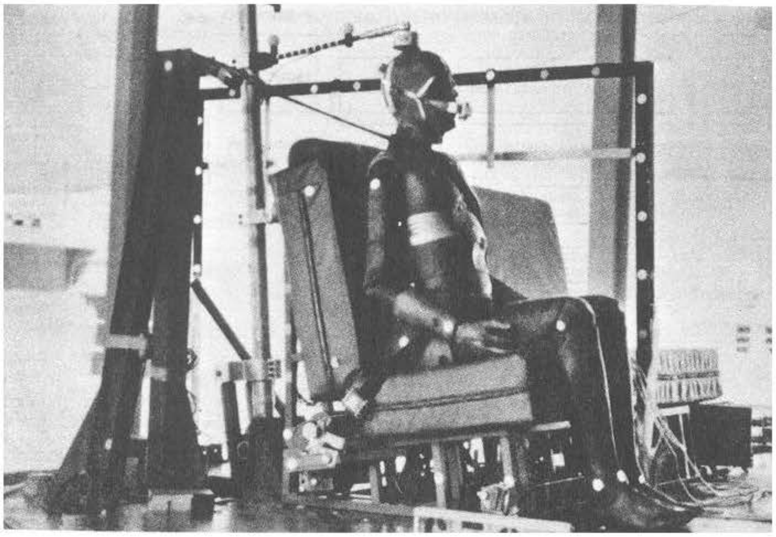


Figure 1. The impact sled.

Sensors. Impact tests are expensive. It is desirable to make as much data measurements as possible in each test. In a thoroughly instrumented impact test, up to 40 sensors may be used for the test subject and the test vehicle (or sledY. For example, nine accelerometers may be used to measure the head kinematics and ten accelerometers may be used to monitor the impact of the chest. Other commonly used sensors include subminiature rate gyros, load cells, potentiometers, inductive devices, etc.

Most of the sensors are constructed in a balanced-bridge configuration with very low sensitivity. When these signals are carried through a few hundred feet of “whip cable” consisting of multiple conductors, the noise level is generally high unless on-board amplification is used.

The Society of Automotive Engineers (SAE) established four filter classes for the data measurement [3]. They are designated as classes 1000, 600, 180, and 60. Each class applies to a different type of data channel. For example, class 1000 is used for the occupant head acceleration while class 60 is used for the sled acceleration.

Inter-Range-Instrumentation-Group (IRIG) format B timing signal is normally recorded on both the instrumentation tape and the high-speed camera film. A data zero-time reference is also provided by an electromagnetic pickup device triggered at a prescribed location along the track immediately prior to impact. This device provided a sharp pulse for the electrical instruments and a flash of light for photographic instruments.

Data System. The electronic data train used to sense, amplify, filter, digitize, encode, record, playback, decode, and input the computer is shown in Figure 2. It is designed for automatic data flow to reduce manual labor and to improve system accuracy. Although high speed photography is simple and useful, film data’reduction is expensive. However, a few photographic data are required to provide initial conditions and final trimming conditions for the electronic sensor data.

Figure 2a shows the data acquisition and recording schematic. Sensor signals are amplified and filtered by integrated instrumentation amplifier boards. They are designed to provide quick gain and frequency changes by selecting a gain resistor and a filter capacitor respectively.

Conditioned signals from all channels are combined by the Pulse-Code Modulation (PCM) encoder which directly samples and digitizes all the analog data prior to transmission. Through this technique, all the sensor data are able to be transmitted and recorded over a single link (drag cable) since all data are time-multiplexed in the PCM approach. High accuracy and self-calibration are also provided because of the encoding process. The sampling rate varies depending on the particular sensor signal frequency spectrum. For example, accelerometers mounted on the head of the subject are sampled at 2000 samples/sec while the seatback deflections are sampled at 500 samples/sec.

Errors associated with analog-to-digital conversion are below 0.2%. However, the 7-bit words (one other bit for parity) are limited by the quantization error of 0.78%.

Because of the simplicity of the PCM system, the drag cable contains only two conductors and the tape recorder only requires two tracks (one for IRIG time code and one for data). However, a redundant system consisting of two additional wires and two additional recording tracks is used for backup purposes.

Figure 2b shows how the test run raw data are played back immediately after the impact. These “quick-look” data provide the test conductor sufficient information to decide whether the test run was valid and provide a basis for performance evaluation of the data processing program.

Figure 2c shows how the field recorded PCM magnetic tape is reformatted into a 7-track digital computer compatible tape which, in turn, is filed for record.

Figure 2d shows the data processing procedure which provides three outputs for each test run, i.e., a set of output listings, a set of output plots, and a set of punched cards of selected variables for statistical analysis.

The PCM Encoder. The Pulse-Code-Modulation (PCM) data system used at the Daisy Track was originally designed for a missile program. It accepts as many as 112 analog inputs and 91 bi-level inputs. Each analog input channel accepts and encodes any input from 0 to 5 volts. Signals less than zero volts are encoded as zero and signals greater than 5 volts are encoded as 5 volts. For each bi-level input channel, signals of 3.03 volts or higher are considered as a binary “one”, and signals of 2.97 volts or lower are considered as a binary “zero”. Overvoltage is protected up to ± 40vdc. Overvoltage on a channel does not affect any other channel accuracy. Input impedance of the encoder is greater than 10 megohm shunted by a maximum of 40 pico-farad capacitance.

The nominal bit rate is 304,000 bits per second. The bit rate error is less than ± 0.5%. Each sample of the analog input voltage is digitized into a seven bit binary word. Following each 7-bit word, there is a parity bit which ensures that each 8-bit word contains an odd number of binary “ones” for error detecting purposes.

Frame synchronization is provided to allow the use of a standard PCM decommutator for resolving the transmitted bit stream into individual data words. Each frame consists of one 16-bit synchronization word followed by seventy four 8-bit data words for a total of 608 bits per frame. Figure 3 illustrates the prime (main) frame arrangement. The prime frame rate is 500 frames per second. Ten analog data words, frames A1X through A10X, are sampled at 1000 samples per second super-commutation rate. This sampling rate can be doubled again by cross-strapping four words to a channel, e.g. words WD-2, WD-21, WD-40, and WD-59, for 2000 samples per second. The channel and sampling rate arrangement is flexible for various experiments.

Eight words are reserved for sub-frames SF-1 through SF-8. The subframe pattern is transmitted during frame number one (word number 1) and repeated at intervals of 20 frames as shown in Figure 3. The sub-frame synchronization code is an 8-bit word. Figure 4 shows the sub-frame arrangement.

Output format of this encoder is a serial NRZ-level (IRIG standard) with the “one” level represented by 2 ± 0.1 volts and the “zero” level represented by 2 ± 0.1 volts. Information bits are transmitted in order of decreasing signifcance (most significant bit first). The output circuit is also protected against open or short circuit. The output impedance is less than 1000 ohms with up to 50 pico-farad loading. The serial NRZ-level output is filtered through a low pass filter having a maximally linear phase response characteristic. Mechanical specifications of the encoder include: size 4"x4"x3", weight 55 ounces.

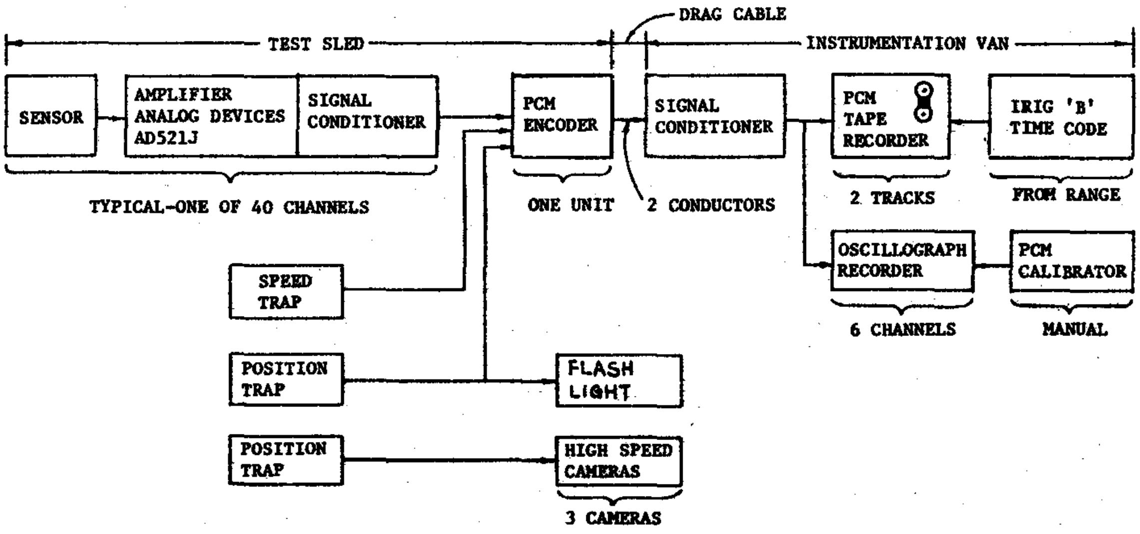
Conclusions. Advantages of the PCM system over the FM system, in the impact sled tests, have been demonstrated. The PCM system requires only one magnetic tape track and one pair drag cable while the FM system requires one tape track and one drag cable conductor per data channel. Furthermore, the PCM system has very simple calibration procedure and is simple for feeding into digital computers. In the car-to-barrier or car-to-car crash test runs, the PCM data can easily be telemetered to a remote site by pulse modulating a radio frequency carrier while the FM data must be telemetered by FM/FM technique if the use of drag cable is to be avoided. The PCM system transmission is virtually immune to noise.

References.

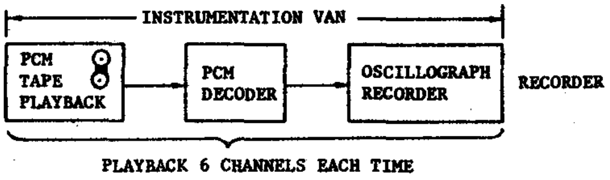
1. J.J. Jachman, “The application of aerospace techniques to automotive crash test instrumentation,” Proceedings of International Telemetering Conference, pp. 362-69, 1973.

2. T.C. Mercer, “Method and apparatus for collecting impact test data,” Proceedings of International Telemetering Conference, pp. 377-385, 1974.

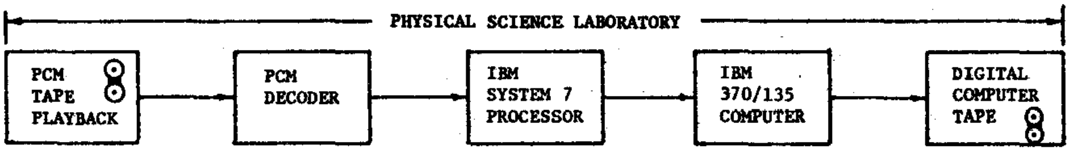
3. “Instrumentation for impact tests -- SAEJ211a,” SAE Recommended Practice. 1975 SAE Handbook, pp. 1363-64, Society of Automotive Engineers, Inc., Warrendale, Pa.



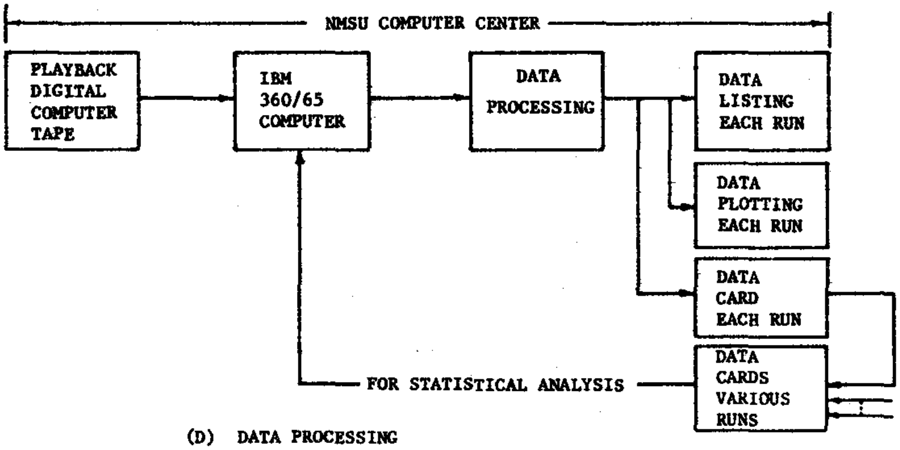
(A) DATA ACQUISITION AND RECORDING



(B) RAW DATA PLAYBACK



(C) COMPUTER TAPE FORMATTING



(D) DATA PROCESSING

Fig. 2. Data acquisition, recording, and processing systems.

PRIME FRAME

16 BIT FRAME SYNC. WD- 0		SF-1 WD-1	A1X WD-2	A2X WD-3	A3X WD-4	A4X WD-5	A5X WD-6	A6X WD-7	A7X WD-8	A8X WD-9	A9X WD-10	A10X WD-11	A11 WD-12	A12 WD-13	A13 WD-14	A14 WD-15	A15 WD-16	A16 WD-17
A17 WD- 18	A18 WD-19	A19 WD-20	A20 WD-21	A21 WD- 22	A22 WD-23	A23 WD-24	A24 WD-25	A25 WD- 26	A26 WD-27	A27 WD-28	A28 WD-29	A29 WD- 30	A30 WD-31	A31 WD-32	B-1 WD-33	B-2 WD-34	SF-2 WD-35	SF-3 WD- 36
SF-4 WD- 37	SF-5 WD-38	SF-6 WD- 39	A1X WD-40	A2X WD- 41	A3X WD- 42	A4X WD-43	A5X WD- 44	A6X WD- 45	A7X WD- 46	A8X WD- 47	A9X WD-48	A10X WD- 49	A32 WD- 50	A33 WD-51	A34 WD- 52	A35 WD- 53	A36 WD- 54	A37 WD- 55
A38 WD- 56	A39 WD- 57	A40 WD-58	A41 WD- 59	A42 WD- 60	A43 WD- 61	A44 WD-62	A45 WD- 63	A46 WD- 64	A47 WD- 65	A48 WD- 66	A49 WD- 67	A50 WD- 68	A51 WD- 69	A52 WD-70	B3 WD- 71	B4 WD- 72	SF-7 WD- 73	SF-8 WD- 74

NOTES:-

1- "SF-1" INDICATES SUBFRAME ONE.
2- "X" INDICATES INTERNAL CROSS STRAP OF CHANNELS; e.g. A1X WD-2 WOULD BE CROSS STRAPPED TO A1X WD-40
3- "B" INDICATES BI-LEVEL WORD.
4- "A" INDICATES ANALOG WORD.
5- "WD-1" INDICATES WORD ONE OF PRIME FRAME

Fig. 3. PCM Main frame arrangement.

SUB-FRAMES

SF-1		SF-2	SF-3	SF-4	SF-5	SF-6	SF-7	SF-8
SUB-FRAME SYNC 1-0	F-8 1-10	G-1 35-0	G-10 36-0	G-19 37-0	H-1 38-0	H-5 39-0	H-9 73-0	H-13 74-0
BI-LEVEL FL-1 1-1	BI-LEVEL FL-3 1-11	G-2 35-1	G-11 36-1	G-20 37-1	H-2 38-1	H-6 39-1	H-10 73-1	H-14 74-1
F-1 1-2	F-9 1-12	G-3 35-2	G-12 36-2	G-21 37-2	H-3 38-2	H-7 39-2	H-11 73-2	H-15 74-2
F-2 1-3	F-10 1-13	G-4 35-3	G-13 36-3	G-22 37-3	H-4 38-3	H-8 39-3	H-12 73-3	H-16 74-3
F-3 1-4	F-11 1-14	G-5 35-4	G-14 36-4	G-23 37-4	BI-LEVEL HL-1 38-4	BI-LEVEL HL-2 39-4	BI-LEVEL HL-3 73-4	H-17 74-4
F-4 1-5	F-12 1-15	G-6 35-5	G-15 36-5	G-24 37-5				
BI-LEVEL FL-2 1-6	BI-LEVEL FL-4 1-16	G-7 35-6	G-16 36-6	G-25 37-6				
F-5 1-7	F-13 1-17	G-8 35-7	G-17 36-7	G-26 37-7				
F-6 1-8	F-14 1-18	G-9 35-8	G-18 36-8	G-27 37-8				
F-7 1-9	F-15 1-19	BI-LEVEL GL-1 35-9	BI-LEVEL GL-2 36-9	G-28 37-9				

NOTES:-

1- WORD NOS; e.g. 1-0 INDICATES PRIME WORD 1, FRAME NO. 0.
2- BI-LEVEL CHANNELS ON SUB-FRAMES ARE IDENTIFIED AS 1-1-N WHERE N IS THE BIT NUMBER WITHIN THE WORD.

Fig. 4. PCM sub-frame arrangement