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AEC Research and Development Report

ELECTRONIC INTERFERENCE
REDUCTION IN ACOUSTIC
EMISSION TESTING

November 1971

BNWL-1596

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Under Contract AT(45-1)-1830

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U.S. Department of Commerce

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By

T. J. Davis
Applied Physics and Instrumentation Department

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ELECTRONIC INTERFERENCE REDUCTION IN ACOUSTIC EMISSION TESTING

T. J. Davis

SUMMARY

This report describes techniques which may be used to significantly enhance signal-to-noise ratio for acoustic emission monitoring in severe electrical environments. Methods for applying common mode rejection and optimizing signal shielding and grounding are presented. A new and useful approach for isolating instruments from unregulated 60 Hz power lines is also discussed.

INTRODUCTION

Acquisition and processing of acoustic emission signals magnify the problems of noise* and interference that are commonly associated with instrumentation systems. This is due primarily to the small intensity of typical emission signals, which at times require a voltage amplification of 90 dB before they are of sufficient magnitude for processing. Another contributing factor is that many acoustic emission tests must be conducted in an environment of heavy electrical activity, must transmit signals over long distances, and must draw their power from raw 60 Hz supply lines. Examples include the monitoring of pressure vessels, particularly nuclear reactor vessels, and generally any metallic structure that forms a ground return for electric currents or is a recipient of radiated electronic transients.

This report summarizes a study directed toward improving noise immunity in acoustic emission systems. Two major categories are discussed: signal processing techniques and an efficient, practical method of achieving power line isolation.

* The term "noise" in this report refers to unwanted electrical signals arising from sources outside the signal amplifiers. It is assumed that amplifiers are optimally designed for lowest internal noise.

SIGNAL ACQUISITION PROBLEMS

Three major sources of unwanted noise in acoustic emission applications are: 1) voltages in the structure being monitored, 2) voltages induced in signal input leads by electromagnetic radiation, and 3) transients on 60 Hz instrument supply lines.

SPECIMEN VOLTAGES

Voltage gradients in a metallic structure being monitored will be encountered to some degree in virtually all acoustic emission applications, including those where the structure is grounded. This results because there is never zero impedance between two points in a metal object. If a current is flowing between the points, there will be a voltage (although minute) dropped between these points. The net result is that a voltage difference will exist between the transducer mounting point on the structure and the amplifier input ground for even small levels of electrical activity in the surrounding area. Connecting these two points together with the ground shield of a signal cable does not eliminate the problem. Rather, it creates a ground loop current as shown in Figure 1. This current drops a voltage in the shield between transducer and amplifier, thereby inserting an unwanted voltage in series with the transducer voltage. This voltage can be ruinous in the many acoustic emission applications requiring amplifier gains on the order of 90 dB.

FIGURE 1. Conventional Acoustic Emission Input Circuit

A piezoelectric transducer (which must generally be used for acoustic emission because of its high sensitivity) compounds the problem. Its front surface electrode forms a capacitor with the test specimen surface unless a thick and thereby attenuative lens is used. This capacitor will couple high frequency components of structure voltages onto the transducer electrode, thereby nullifying the gains made by electrically floating the transducer off the specimen.

INDUCED VOLTAGE IN SIGNAL LEADS

Voltages induced in signal leads between transducer and amplifier are a more serious problem in acoustic emission applications than in most other types of instrument systems. Again this is due to the small input signal level of many applications and consequent large amplifier gains required.

Acoustic emission data often must be acquired from a specimen located in areas of high electromagnetic field strength. Examples are monitoring industrial plant structures located adjacent to high-current power cable runs, and monitoring inert gas welds of circular specimens which are rotated through the arc. The latter are almost invariably provided with vari-speed rotational drive by universal ac-dc brush motors with their inherent commutator arcing. Further complications arise when the motor is driven by a thyristor speed controller whose output contains rapid current transitions. Both commutator arcing and current transitions can cause radiation of energy over a broad frequency spectrum.

SUPPLY LINE TRANSIENTS

Supply line transients of considerable amplitude can be found in any area where high current loads are switched to and from the 60 Hz supply lines. Some acoustic emission investigators have found that isolation transformers and even line regulator transformers have been of limited value in reducing the effect of these transients.

SOLUTIONS

THE COMMON MODE SYSTEM

Interference from structural voltages and voltages induced in the signal leads has a common remedy. This remedy is the use of a two-element balanced transducer, a three-wire input system, and a differencing amplifier with good common mode rejection over its complete bandwidth. Such a circuit is shown in Figure 2.

This type of input system has long been used for low frequency or dc signals, but the higher frequency signals characteristic of acoustic emission apparently have dampened attempts to use the system for acoustic emission. It may, however, be put beneficially to use if special attention is given to certain design considerations. In one case, we achieved a 37 dB increase in signal-to-noise ratio by replacing a conventional two conductor input system with a three conductor, common mode system.

FIGURE 2. Common Mode Rejection for Acoustic Emission Testing

EFFICIENT BATTERY POWER SYSTEMS

Supply line transient problems can be eliminated by converting to a completely floating system powered by batteries. This practice frees all of the system electronics, with possible exception of chart recorders, from a poorly regulated power line and its undesirable influence on the emission data.

The primary impediment to this approach is potentially short battery charge life and long recharge times. An expedient solution to this problem is the use of silver cadmium batteries coupled with a fast charging circuit. The energy/unit volume of silver cadmium batteries is among the highest of any available. For example, a 5 A-hr 3.2 V battery examined measured only 1-1/4 x 1-1/4 x 4 in. in size. A technique was developed under this study by which this same battery could be safely recharged in 5 hr. The battery manufacturer did not feel that fast charging would significantly reduce the battery's useful lifetime.

This battery and fast charge combination makes it possible to operate a typical single-channel emission system for 10 hr while two separate battery packs could be recharged in that amount of time. Fifty hours of continuous operation could be attained with a system designed for low current consumption (100 mA).

THE COMMON MODE SYSTEM

The common mode input system of Figure 2 attains a high degree of immunity to both off-ground structure potentials and induced signals, since the amplifier responds only to the difference in voltage at its input terminals. Potential differences between amplifier ground and structure ground are common to both amplifier inputs and do not evoke an output response. Similarly, incoming radiation or ambient fields will induce an equal voltage in both signal leads. The net result is that unwanted signals common to both inputs will not pass through the amplifier, while transducer signals pass through for amplification because they represent a voltage difference at the amplifier terminals.

As previously mentioned, common mode rejection has not been extensively applied to high frequency systems because of the inherent circuit design difficulties. A large common mode rejection ratio (CMRR) is difficult to achieve at high frequencies because of minutely unequal phase shifts in plus and minus amplifier channels. Several conventional difference amplifier circuits which we investigated exhibited very substantial decreases in CMRR with increasing frequency. Lacking an adequate conventional design, the differencing amplifier of Figure 3 was developed.

FIGURE 3. High Common Mode Rejection Ratio Acoustic Emission Preamplifier

The circuit of Figure 3 exhibits a CMRR of 70(37 dB) from 1 MHz to its upper 3 dB point of 8 MHz. The CMRR increases to 250(48 dB) at lower frequencies, as shown in Figure 4. The differencing amplifier portion of the circuit (Q3 and Q4) is preceded by FET source follower preamplifiers (Q1 and Q2) for high input impedance. A cable driver amplifier with a gain of 10 follows the differencing amplifier.

The differencing amplifier developed is a unique complementary pair combination which frees the design from limitations of the conventional differential amplifier. The conventional differential amplifier employs two common-emitter amplifier transistors of the same polarity with both emitters tied to a constant current sink. The conventional circuit, in addition to its current biasing complexity, has a CMRR which falls off rapidly with increasing frequency because of stray capacity in the current sink element.

FIGURE 4. Common Mode Rejection of the Preamplifier Shown in Figure 3

The differencing amplifier of Figure 3 does not require current sink biasing and consequently preserves CMRR to its upper bandwidth. It is also free from the base emitter cutoff problems of noncurrent-biased, single polarity amplifiers, since an input-caused change (increase or decrease) in the collector current of one transistor causes a corresponding change in the other transistor. Thus an increase in conduction on one side causes a similar increase in the other side, instead of driving it towards base-emitter cutoff.

Signals at input B excite transistor Q4 in the common emitter mode, with the output being $-\frac{R_2}{R_1} E_B$. Signals at input A are applied to R_1 by emitter-follower action of Q3. This constitutes a common base drive to Q4, whose collector output will be $\frac{R_2}{R_1} E_A$. Choosing $R_1 = R_2$, the amplifier output is $E_A - E_B$. Capacitor C3 provides emitter peaking for Q4 to reduce the effect of its Miller capacitance at high frequencies, thereby preserving CMRR. Transistor Q3, operated in the common collector mode, is relatively immune to the Miller effect.

Optimum shielding and grounding of the three-wire common mode system is shown in Figure 2. The circuit consists of a dual element transducer grounded to the test specimen at the centertap. Signals are passed to the amplifier through a shielded, twisted pair. After common mode rejection, the signals are given adequate gain to put them well above any interference which may be coupled in between the amplifier and signal processing electronics.

Established shielding and grounding theory dictates that there be no closed loop in the shield connections between sensor and amplifier grounds. This does not fully apply to this acoustic emission input circuit as best results were obtained with the completely closed ground loop shown. Theory maintains that the ground loop current flowing through the signal shield couples stray signals onto the input leads through distributed capacitance. We have found the effects of opening the loop to be much worse, because the potential difference between grounds No. 1 and No. 2 often exceeds the

common mode input voltage of any practical amplifier. The closed loop in the shield very effectively reduces this potential difference, permitting full advantage of common mode rejection.

Construction and use of a dual element transducer is not a serious impediment. With respect to polarization of the piezoelectric stock, the elements should be connected in series aiding and not series opposing. The author has successfully used two identical elements side by side as shown in Figure 5a. For narrow band emission signals this combination will be direction sensitive. However, most acoustic emission signals are sufficiently broad banded to nullify this problem. A dual element design insensitive to the direction of incoming signals is shown in Figure 5b.

FIGURE 5. (a) Dual Element Transducer Shown in Housing
(b) Dual Element Transducer Insensitive to Direction of Incoming Signals

This transducer is made by cutting a polarized, circular piece of stock into two concentric sections of equal surface area, and overturning one of them before potting.

BATTERY POWER FOR ACOUSTIC EMISSION SYSTEMS

As described previously, the advent of high energy/unit volume silver cadmium batteries, coupled with the fast charging technique described below, renders the complete operation of acoustic emission system on batteries very attractive.

The charge curve of a Yardney Silcad[®] battery is shown in Figure 6. This battery is rated at 3 V nominal with 50 A-hr of energy capacity and may be safely discharged with a load current of 0 to 5 A. Four of these batteries provide a very compact 12-V power pack for an acoustic emission system.

The manufacturer's data recommends a charge current of 0.2 A maximum, which would require a 25-hr recharge time. We found these batteries can be safely recharged in 5 hr (1 A of charging current) if certain precautions are taken. No evidence has been found that fast charging reduces the battery's lifetime of charge-discharge cycles, and the manufacturer generally concurs with this. It is noteworthy to add that fast charging of nickel-cadmium batteries is becoming quite common. Nickel-cadmium batteries, however, possess a significantly smaller energy/unit volume figure than silver-cadmium.

A discharged 3-V silver cadmium cell will possess a terminal voltage in the range of 3.2 V or lower, Figure 6. At about 30% of full charge the terminal voltage rapidly climbs to a new plateau of approximately 4.5 V. It remains there until full charge is reached and outgassing commences. At this time the terminal voltage begins another upward transition. This second transition continues only as long as charging current is applied. When charging current is ceased, the terminal voltage drops back to 4.3 V.

[®] Registered tradename

FIGURE 6. Charge Curve of a 3.2 V, 5 A-hr Silver Cadmium Battery

Fast charging of Silcad[®] batteries is achieved by exploiting the characteristics of this second plateau. The manufacturer recommends that charging current be terminated when the terminal voltage reaches 4.60 to 4.75 V with the 0.2 A recommended charge current flowing. The author has found that larger charge currents (1 A) still do not generate this second plateau until a full charge is attained. Thus, the prime criteria for fast charging is the ability to rapidly and precisely detect the second plateau and terminate the charge current before excessive outgassing takes place. The Silcad[®] is vented to relieve internal pressure so the threat of explosion is not present. Outgassing reduces the battery's lifetime severely, however.

The circuit of Figure 7 was developed to control the fast-charging of silver cadmium batteries. It consists of a Schmitt trigger, Q1 and Q2, with a preset hysteresis. This circuit provides a go/no-go control of charging current through gate driver Q4 and SCR 1. Its operation is as follows:

- During charging, Q1 and hence Q5 and Q6 are OFF, allowing SCR 1 to half-wave rectify 60 Hz voltage onto the battery.

FIGURE 7. Fast-Charging Circuit for Silver Cadmium Batteries

- When the averaged terminal voltage exceeds 4.70 V, Q1 is turned ON, and Q2 is turned OFF. Transistor Q6 turns Q4 ON, shorting the gate of SCR 1 to ground and holding it OFF. At the same time, Q3 has been turned ON, reducing the reference voltage at the base of Q2.
- Hence the charge circuit cannot be reactivated until the battery voltage falls below 4 V, or until it is manually restarted.

The Schmitt trigger function can be achieved more easily with an integrated circuit voltage comparator, but plus and minus supply levels are required to power the device, rendering its use less practical.

CONCLUSIONS

The major helpful techniques in interference reduction are as follows:

- Employ a balanced three conductor system with dual element center-tapped transducers, a shielded twisted pair connection between transducers and preamps, and a differential preamp with good common mode rejection over its bandwidth.

- Employ battery powered instruments where practical.
- For quieting noisy ac-dc brush motors, ground one of the brushes if possible.
- If the motor is driven by a thyristor speed controller, place a large capacitor (500 to 1000 μ F) across both brushes and field. Be sure to observe polarity for the electrolytic capacitors. If the motor is to be operated in both forward and reverse, then only the supply which maintains the same polarity (armature or field) may be filtered with electrolytics.

ACKNOWLEDGEMENTS

I would like to acknowledge the assistance and contribution of C. B. Perry in development of the prototype circuitry.

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