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Acoustic Signal Analysis for Noise Source Identification in Mechanisms

Abstract: Proper interpretation of the time and frequency characteristics of machine noise provides information useful in identifying and quantifying noise sources in complex mechanisms. The use of commercial acoustic instrumentation led to the development of unique analog instrumentation for noise-time analysis and ultimately to a real-time analog-digital signal analysis capability. The hybrid system described in this paper provides the time and frequency resolution necessary for noise source identification and evaluation.

Introduction

With the concern for ecology and our environment, a great deal of attention has been given to the subject of noise. Significant acoustical noise can be generated by data processing equipment, especially input/output devices such as impact printers and card readers.

Some of this noise can be reduced by machine covers and absorption materials. However, it is usually most effective to reduce noise by eliminating it at its source. The first step in this kind of noise reduction is to locate the noise sources and determine their contribution to the total machine noise. In complex electromechanical equipment, this is a challenging task.

Several techniques can be used for noise source identification. One procedure is to establish the physical location of the noise source. A movable probe microphone or a correlation technique using multiple microphones locates the area in a machine where a significant noise occurs. This procedure is useful but the significance of the noise must be weighted relative to the operator's position at a covered machine. Measurements near a source may be misleading when their contribution to the quantitative noise level of the complete machine at the operator's position is to be estimated.

A second commonly used procedure for noise source identification is to analyze the frequency spectrum of the measured noise. If individual noise sources can be identified with particular frequency bands, either through operating frequency or resonance considerations, a frequency analysis of the noise signal can be used to establish the significance of the various noise sources. This technique is particularly useful with rotating equipment. With more complex vibrations and impacts, and when much of the noise is radiated by supporting structures, the noise frequencies cannot always be correlated to the repetition rate of a mechanism.

A third procedure for quantitative identification requires disabling the particular function suspected of being a significant contributor to the overall noise level. Machine measurements, with and without disablement of a suspected function, are a positive indication of the quantitative significance of a source. Two difficulties are encountered with this procedure: 1) Disabling some functions of a machine may require extensive model work, and 2) normal operation of the machine is not possible with certain basic functions disabled.

Analysis of noise in the time domain is a particularly useful additional technique. If the noise from a machine is displayed as a function of time, the noise can often be correlated to and identified by the associated function of a machine (e.g., through a machine timing diagram). Analysis of noise in the time domain is especially well suited for evaluating mechanical devices. It can be used to identify significant noise sources at a position where a machine operator would stand or sit and can also be used near a noise source to determine what part of a device's function causes noise. Many mechanism noise

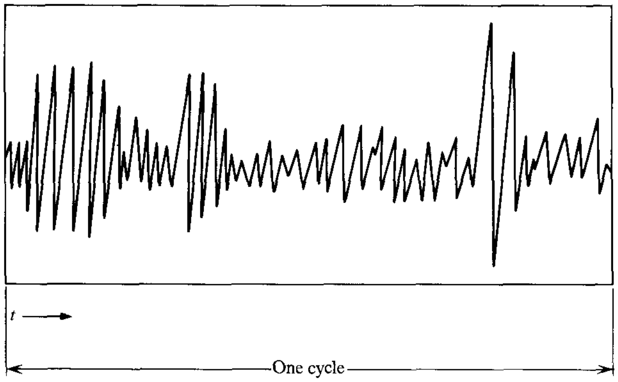
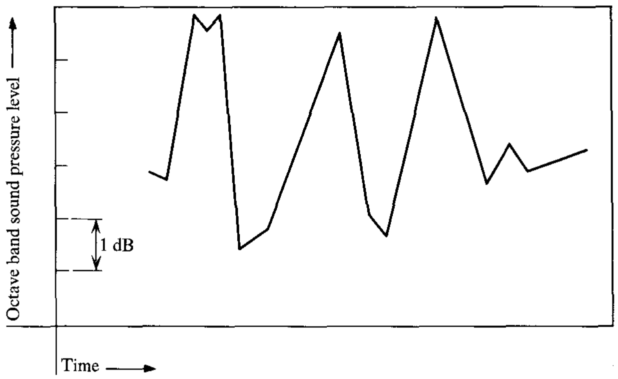


Figure 1 Oscilloscope record of acoustical waveform for one machine cycle.

Figure 2 Octave band noise vs time plot, typical of the oscilloscope approach.



sources that cannot be distinguished by their frequency characteristics can be separated and identified by time analysis. In addition, the procedure can quantify sources and predict the significance of redesign without extensive modeling or modification of the machine.

This paper discusses methods that can be used to study the noise from machines as a function of time. Two unique methods are discussed in detail:

1. A procedure to repeatedly subtract a portion corresponding to a particular small time segment from the measured acoustic signal of a cyclical noise. The remaining signal is then analyzed with conventional analog acoustic instrumentation.
2. A hybrid approach, which uses analog instrumentation to detect, amplify, and filter the noise and a digital computer system to store, process, and display the data. This approach results in a "soundprint" displaying machine noise amplitude and frequency vs time.

Discussion

All machines developed and marketed by IBM have specified maximum noise levels. The criterion used is the ISO (International Standards Organization) Noise Rating (NR) method. This method requires measurements of rms sound pressure levels in octave band frequencies. The frequency range includes eight octave bands from 63 Hz to 8000 Hz midfrequency. The rms sound pressure levels are expressed in decibels (dB), re: 20 $\mu N/m^2$. Each frequency band is weighted differently and the resulting most significant band(s) determine the NR level of the machine. To define the significance of a noise source, both the frequency and energy (rms) content of its noise must be determined.

Commercial equipment is available to perform the acoustical analysis. Limitations, however, become significant in attempting to apply this equipment to time-domain dynamic analysis. These limitations have led to the development of unique techniques for this analysis, which have been previously reported [1].

• *Oscilloscope Approach*

The basis of the previously reported approach was to use an oscilloscope to display the instantaneous sound pressure from a machine (Fig. 1). The technique was useful and significant refinements have been described [1], but it was difficult to determine quantitative information. The first difficulty is that the rms contribution of the noise bursts must be established. A rough estimate of rms values can be made by visual observation of the instantaneous noise levels. However, since rms measurement includes integration of the square of the instantaneous magnitude over a period of time, quantitative values are difficult to obtain. The quantitative values were obtained in this earlier technique by manually digitizing a large number of points on a photograph of the waveform and using a computer to calculate the rms levels (Fig. 2). Although workable, this is a time-consuming process.

To isolate the significance of a noise source, its contribution to the NR level of the total machine must be determined. This introduces a second difficulty, namely filtering the signal to reduce it to the required frequency bands. The rms digitization-calculation procedure must be applied eight times to obtain the necessary octave band data.

Because of these factors, the oscilloscope approach has its greatest value in obtaining preliminary, qualitative information.

• *Subtraction technique*

An entirely different approach was taken to overcome some of the basic limitations noted in the previous section. Most mechanism noise is cyclical, or can be made cyclical through proper machine operation or use of tape loops, and this is the basis of the subtraction approach shown in the simplified diagram of Fig. 3. If this circuit (Fig. 3) were applied to the signal of Fig. 1, the result would be as shown in Fig. 4.

Basically, the circuit passes the input signal without modification at all times except the interval Δt. During Δt, a resistive attenuator is electronically switched into the circuit, producing attenuation of the signal. Both the location and duration of Δt, as well as the amount of attenuation, are variable.

Two things should be noted here: 1) A portion of the signal (during Δt) is attenuated during each cycle of the cylical noise, and 2) no reactive elements are used in the circuit. The output is an accurate reproduction of the signal in level, frequency, and phase except for the selected time segment of width Δt, when the resistive attenuation controlled by a high speed electronic switch is engaged to reduce the level.

The signal output can be used as the input to any form of conventional acoustical analysis equipment. The measurement could include impact, frequency spectrum, overall level with a weighting network, or other systems for determining objectionability or signal content. The time constants of the instrumentation are not critical since the cycle can be repeated as many times as required to get a satisfactory reading.

The acoustical analysis equipment records the level of the signal with attenuation section Δt cyclically repeated. This procedure effectively predicts the measured sound level of the machine with improvements that would reduce the noise during Δt by an amount indicated by the attenuation level. Any inaccuracies in the measured quantities that result because of the inability of the instrumentation to respond to the dynamic signal are exactly those that would result following a machine improvement to reduce the acoustical noise during Δt. In effect, by suitable selection of the time increment Δt, and the associated attenuation level, the largely nondynamic analog instrumentation is capable of predicting the significance of a dynamic noise source defined in time.

The subtraction technique is useful to quantitatively study machine improvements that are significant on a time scale, but it does not provide noise-time plots for use in source identification. This requires an additional step.

Consider the effect of locating Δt (Fig. 4) progressively throughout the machine cycle. The electronic switch-attenuator output could be used to determine whether noise is excessive (objectionable) at any point. If we assume that NR is used as the indicator of objectionability, the octave band levels would be measured for each time T of the cycle with the signal attenuated during Δt. From this, NR levels could be obtained. Plotting these NR levels against T (where the interval Δt begins) would result in a plot such as that shown in Fig. 5. This is a plot of the machine NR level that would result from noise reduction during Δt versus the Δt time location, T.

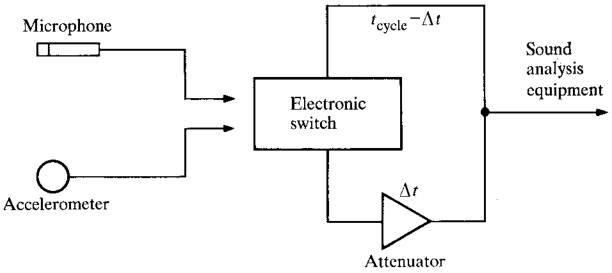


Figure 3 Schematic of subtraction technique.

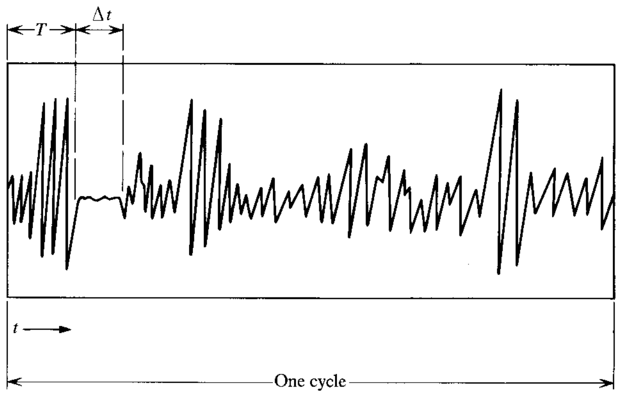


Figure 4 Oscilloscope record of signal from one cycle with attenuated section.

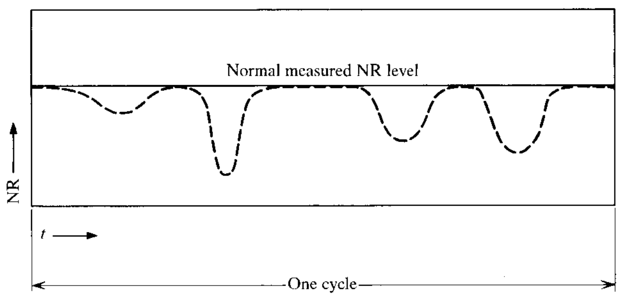


Figure 5 Calculated NR from subtraction technique. The variable T is the time during a cycle at which the attenuation interval Δt begins.

This plot is actually more useful for noise source evaluation than a plot of noise vs time as previously obtained [1] (Fig. 2). The earlier plot establishes the most significant source, but it does not easily predict the overall machine noise level resulting from an improvement that reduces the noise from that source. Figure 5 shows the expected improvement in overall machine-noise ob-

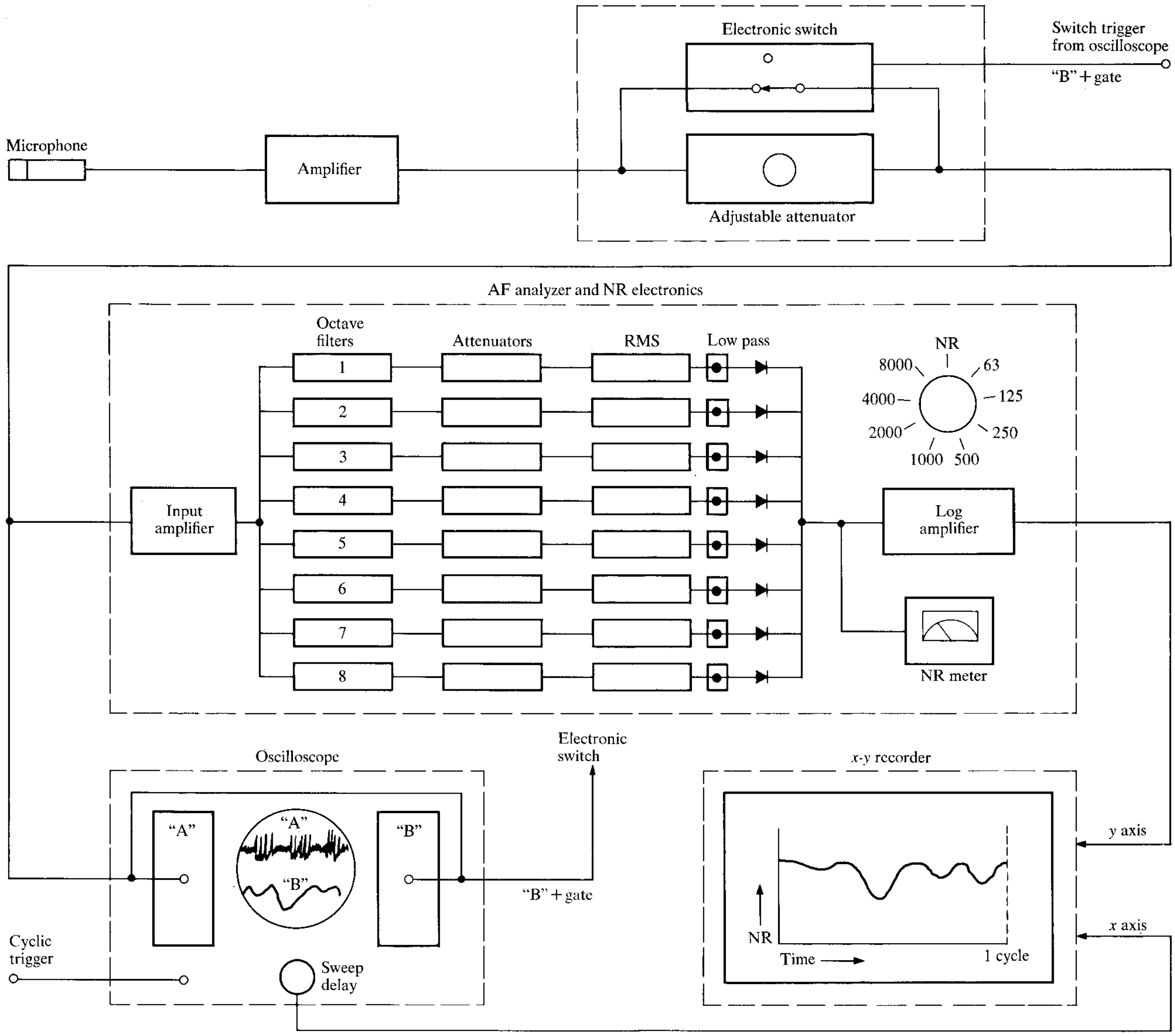


Figure 6 Schematic of electronic switch and NR meter.

jectionability resulting from improvements at time T. This *overall* improvement is the most significant consideration when establishing the quantitative importance of noise sources on a time scale.

• *NR meter*

Determining the NR level by measuring all eight octaves individually and comparing the results with published curves is very cumbersome because of the amount of conversion required to complete a curve such as that in Fig. 5. The NR meter system implements the subtraction technique by direct NR readout. A Brüel and Kjaer Model 2112 Audio Frequency Analyzer* is the principal element in the system (Fig. 6), but special circuitry required for NR analysis and time-cycle NR analysis was added to the analyzer.

*Trademark of Brüel & Kjaer Instruments, Inc., Copenhagen, Denmark.

The NR meter contains basically eight separate octave filters that simultaneously divide the audio spectrum into the eight octave bands. Each filter output is connected to an amplifier that amplifies a particular band according to the predicted objectionability reflected in the NR curves. The rms circuitry and low-pass filter duplicate what is done on a single-channel basis when making NR measurements octave by octave with conventional procedures. Output is to a diode matrix.

The diode matrix parallels the manual procedure of determining the NR level by comparing the measured octave levels with published NR curves and then using the highest-level curve to determine NR level. The diode matrix effectively excludes all other octaves from the determination and the output.

The "A" sweep of the oscilloscope shows the full noise cycle while the "B" sweep shows a Δt selected by using the "B" sweep and sweep delay controls. The "B" sweep "plus gate" drives the electronic switch, which attenuates the signal during the "B" sweep. The attenuated signal is observed on the oscilloscope by monitoring the electronic switch output.

The output from the NR meter is amplified logarithmically and then fed to the y-axis of an x-y recorder. The x-axis is controlled by a special output from the oscilloscope that is proportional to the "B" sweep delay time.

Adjusting the oscilloscope to cyclically display the entire noise cycle automatically adjusts the x-axis of the x-y recorder to the cycle time being studied. This adjustment also controls the cyclic operation of the electronic switch circuit. When the attenuator in the electronic switch circuit is adjusted to a suitable level, and the "B" sweep is set for the desired attenuation time, control of the electronic switch operation is complete. The recorder plot is made by manually adjusting the "Delay" control through the cycle.

With the NR system, a rapid analysis can be made of NR level versus cycle time. A sample NR meter plot using the subtraction technique is shown in Fig. 7. The data are the same as those used to obtain Fig. 2. The previous method took two man-days, while one observer can plot the NR levels in less than ten minutes with the NR meter.

• *Digital approaches*

Several techniques with which a totally digital system can be used to perform the desired analysis are possible, and a number of these were evaluated. The first step is to get a reasonable digital representation of the analog microphone output. The sampling rate used when digitizing the signal must be at least twice the highest frequency of the sampled waveform. These high sampling rates make it necessary to store large amounts of digital data.

To provide a quantitative measurement of the noise level of the machine, a digital rms of the acoustical signal is computed. The flexibility of digital processing provides a selectable integration time for computing the rms, which in turn provides the capability of getting an rms vs time plot. The rms level can be plotted for one or several cycles, and one may then evaluate the effect of eliminating specific noise bursts. The sampling rate used in digitizing the signal and the integration time used in the calculation are the factors controlling the statistical confidence and time resolution of the rms computation.

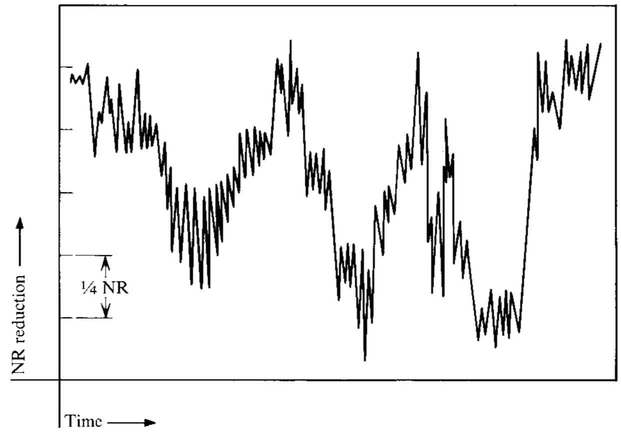


Figure 7 NR meter plot made by the subtraction technique.

Digital processing of signals in the frequency domain requires some kind of "digital filtering." The technique most frequently used is an implementation of the Fast Fourier Transform. For identification of specific frequency components within the signal, the discrete power spectral density plot is the most meaningful. However, it is desirable to have timing and frequency information available simultaneously. This requires a three-dimensional plot showing both frequency and amplitude vs time. In our approach, an overprinting technique on a line printer [2] is used, with the ordinate and abscissa of the printed plot corresponding to time and frequency, and the intensity of printing corresponding to the amplitude within the time-frequency matrix (see Fig. 8). The output picture is similar to the sound spectrograph or sonogram commonly used in signal processing for speech recognition.

There are some disadvantages associated with digital signal processing. The most significant problems are the need for fast sampling rates and a large data storage capacity. With the current interest in real time analyzers, the processing and data display delays in the digital system can be objectionable, particularly in the case of frequency analysis and the averaging of several cycles.

Hybrid approach

For a useful representation of what is occurring in the time and frequency domains, a matrix of values is needed where each value represents a measure of the energy within a time and frequency "window," the complete matrix covering a full machine cycle and all frequencies of interest. To provide the fine time resolution needed for noise source identification, a fast (short integration time) rms detector is required. However, for an accurate measurement of the NR level for a complete cycle, the energy contained in each of the individual time windows must be summed with that of the other intervals. In ad-

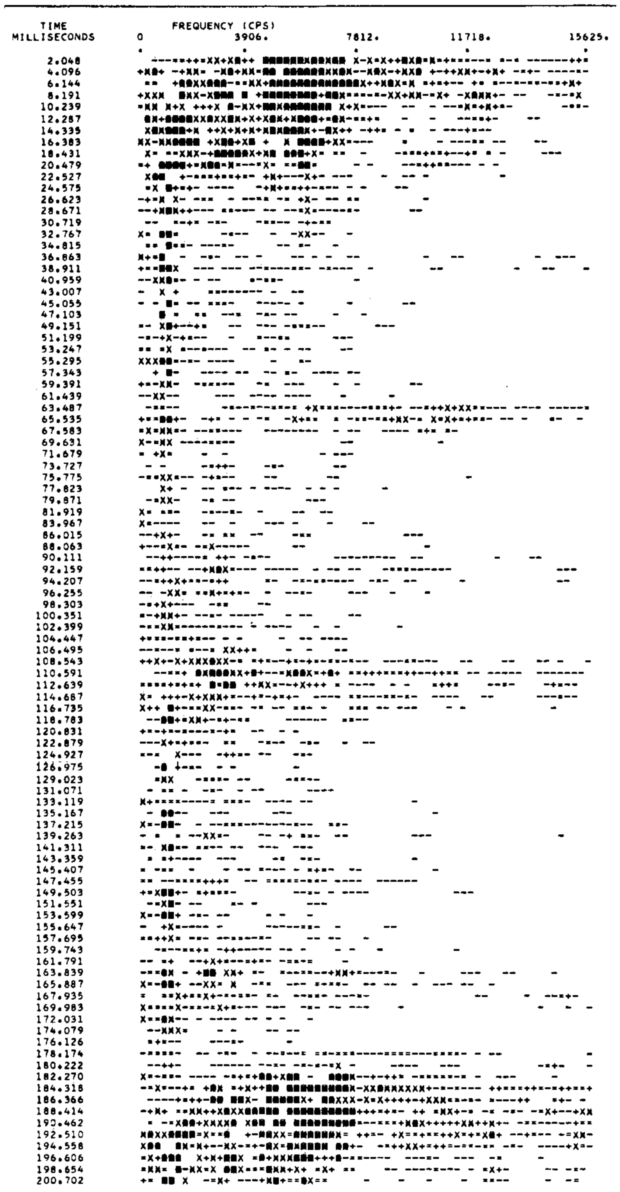


Figure 8 Amplitude-frequency-time plot from line printer.

dition, it is often desirable to average the amplitude-frequency-time information for several cycles to assure a meaningful measurement of acoustic levels under normal operation; the latter can vary significantly from cycle to cycle in mechanisms. Finally, in noise reduction, the investigator must have the analysis data and source identification information available at the completion of each test, so as to evaluate effectiveness and provide improved input for subsequent tests.

The hybrid approach described in this section defines an analysis system that meets all of these requirements. The analog filters and rms detectors provide fast response to accurately describe the energy contained in short noise bursts. Digital energy summation and cycle averaging provide a measure of overall effect on machine noise level. Using this system on-line while experiments are being run provides fast response and the ability to request the output format that most clearly presents the information needed for defining the next testing conditions.

• *Analog circuits*

The hybrid approach was implemented by combining the previously described NR meter with a suitable interface to an IBM 1130 digital computer. The NR system remained largely intact with outputs to the computer provided at the low-pass filter output points of Fig. 6. The necessary modification of the rms section is described below.

Commercial real-time analyzers have generally used two approaches for rms detection that are particularly suited to general purpose applications. The first is to digitize the filter output and digitally compute the rms. This is a particularly accurate approach but requires either multiple samples per cycle of the highest filter frequency or a randomized sampling technique. The latter approach limits the minimum integration period to a length much longer than desired for the present analysis purposes. Multiple samples per cycle of the highest filter frequency impose extreme computer requirements when applied to multiplexed input.

The second approach is to design very highly refined analog rms circuits and digitize the output from these. The trade-off is that highly accurate rms detectors, which have broad frequency response and are capable of high crest factors, are complex and limited in transient response.

In contrast to these approaches, the circuit designed for the hybrid noise-time system is shown in Fig. 9. Essentially, the circuit is a full-wave rectifier followed by an approximate rms detector [3]. The ratio of the rms level of the input signal (E_{rms}) to the dc output (E_{out}) in this circuit is a function of R_2/R_1. The R_2/R_1 ratio used was 2, which gives constant $E_{\mathrm{rms}}/E_{\mathrm{out}}$ for a variety of input wave shapes.

This circuit is relatively simple, but is entirely satisfactory in this application because of other design factors. These factors are: 1) restriction to a narrow frequency band output of the filter, which nearly approaches a simple sine wave, and 2) design of the circuit time constant and digital sampling combination to essentially follow high crest factors and use the computer to integrate in time.

The critical factor in the circuit is in relation to 2) above. An RC time constant of three periods of the center filter frequency for each octave was selected. This means a 375-μs time constant for the 8-kHz octave, which is extremely short. Lower-frequency octaves would have correspondingly longer time constants. The problem then reduces to one of acceptable ripple level. The ripple with a full-wave rectifier under these conditions is less than ±0.5 dB. Although this may seem high when compared with the capability of most laboratory instruments, it is satisfactory for the type of dynamic analysis desired and is a suitable compromise to obtain the desired dynamic response. Actually, the summed readings finally recorded are considerably more accurate because of the statistical nature of the summed samples. To complement the short time constant, each octave band is digitally sampled each 200 μs. (If desired, a much less frequent sample could be taken in the lower frequency octaves because of the proportionately longer time constants.)

The special analog circuits that were designed for the hybrid system are of limited value for any general purpose analog system. Combining these with the complementary digital system, however, provides total system performance that is nearly optimum for the type of noise-time analysis desired.

• *Digital processing*

The use of proper analog preprocessing (i.e., parallel octave band filters and fast rms detectors) has eliminated the most severe restrictions of digital signal processing. The digital sampling procedure is complicated by the fact that there are now eight channels (eight octave bands) to be sampled, but the signal on each channel is a relatively slowly changing dc level proportional to rms and can be sampled at a slower rate. The time-consuming procedures of frequency analysis and continuous rms computation are no longer necessary. The data, as sampled, are already broken into frequency and time windows, forming a matrix of data.

In processing these digital values and preparing the output format, the real benefits of using a digital system become apparent. Correction for any fixed time delay within an octave band is simply a matter of shifting the data values by a specified amount along the time axis. The necessary shift is different for each octave, because of the different delays introduced by the various filters and other analog components.

Cycle-to-cycle variations in frequency, amplitude, and timing can be large when the noise signal from mechanical components is being analyzed. The effects of these variations can be eliminated or evaluated by digitally averaging, point by point, the time-frequency matrices of a number of cycles. The number of cycles to be averaged can be exactly specified to assure statistical confidence in the average, while also assuring that only cycles during which functional operation is closely controlled (or monitored) are included in the average.

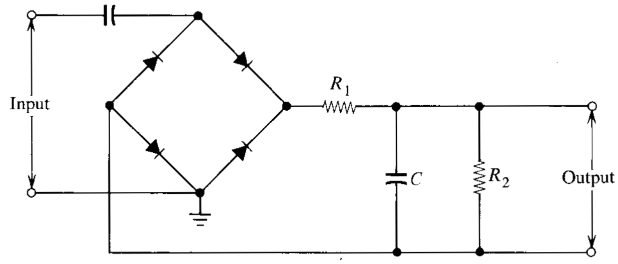


Figure 9 Schematic of refined analog rms circuit.

Once the data have been sampled, shifted and averaged as desired, the output format is prepared for interpretation by the operator. In general, the first printout would be a rather coarse picture covering the full machine cycle, on which major noise peaks and times of interest can be noted. Since the input data are sampled at a rate high enough to include the energy in short bursts, more data points are available than would normally be desired on the printout. The frequency separation is fixed by the octave band filters, but the individual rms-vs-time data points must be combined to provide the rms over the time period included in one printout value. At the same time that the individual printout values are being computed, all values within each octave band can be summed in the same manner to compute the total-cycle NR level for each octave band and, consequently, the overall NR level of the machine.

Finally, by using the stored data taken from the same machine cycle(s) as was the original printout, one can expand a selected section of the cycle. This provides much greater detail for noise bursts and finer time resolution on the data printout. The request for finer resolution can be extended to the limit established by the sampling rate used when collecting the data.

• *Example of application*

In order to demonstrate the use and output of the hybrid approach more clearly, we describe here an example of machine analysis. The tested machine is a high speed 80-column card reader. In actual use, more than one card is in the machine transport at any given time. This leads to multiple noise sources and bursts at given instants. For this test, the operation of the machine was changed so that only one card was processed at a time. A machine cycle in this case is therefore the time required for one card to be selected from the hopper, transported through the machine, and deposited in the stacker. This process takes approximately 160 ms.

Figure 10 shows a portion of a computer printout of a 200-ms machine noise output. This soundprint shows the calculated rms sound pressure level, corrected for NR in the four highest frequency octave bands, during

TIME MILLISECONDS	1000	2000	4000	8000	TIME MAX NR LEVEL	Event
	*** OCTAVE	BANDS	(HZ) *	*		
1.0	48.5	50.5	53.7	54.2	54.2	Hopper magnet seals
3.0	51.9	49.9	57.4	52.9	57.4	
5.0	52.7	48.6	56.3	50.3	56.3	
7.0	50.8	48.1	55.9	48.6	55.9	
9.0	48.2	48.3	52.0	47.6	52.0	Deck lifter hits cards
11.0	47.6	48.0	50.5	46.7	50.5	Hopper magnet restored
13.0	48.3	46.9	52.7	46.4	52.7	
15.0	50.4	47.1	50.1	49.5	50.4	
17.0	50.3	47.8	49.1	50.9	50.9	
19.0	47.7	49.5	54.9	53.4	54.9	Card under eject roll
21.0	47.3	50.9	55.6	54.0	55.6	
23.0	51.2	47.8	57.7	51.9	57.7	
25.0	52.4	47.4	51.5	51.0	52.4	
27.0	49.7	48.8	49.9	52.2	52.2	
29.0	47.6	48.2	49.2	49.2	49.2	
31.0	47.5	48.0	48.2	49.7	49.7	Card hits aligner spring
33.0	48.0	46.5	49.3	48.2	49.3	
35.0	46.7	44.8	48.8	46.7	48.8	Card aligned against top rail
37.0	47.5	47.6	49.3	48.8	49.3	
39.0	49.1	48.9	51.4	49.6	51.4	
41.0	49.8	51.6	56.6	50.6	56.6	Corner station magnet sealed
43.0	49.8	47.6	55.0	50.1	55.0	
45.0	48.9	48.1	56.4	49.8	56.4	
47.0	49.6	45.3	51.2	47.7	51.2	Card at first pressure roll
49.0	47.6	45.6	51.7	48.0	51.7	
51.0	48.3	46.6	49.0	46.6	49.0	Card at read station
53.0	49.9	47.7	47.4	47.7	49.9	
55.0	49.3	43.9	49.6	48.1	49.6	
57.0	47.1	46.9	46.7	45.5	47.1	Card at second pressure roll
59.0	46.2	44.3	48.5	46.6	48.5	
61.0	48.0	46.9	45.0	46.7	48.0	
63.0	49.7	48.7	51.9	48.7	51.9	
65.0	50.8	51.2	58.3	50.5	58.3	
67.0	48.3	49.9	60.2	51.9	60.2	
69.0	47.7	48.7	58.6	50.3	58.6	
71.0	46.4	48.7	59.5	51.0	59.5	Post-read eject magnet seals
73.0	45.7	48.7	58.9	48.7	58.9	
75.0	44.8	46.5	55.2	49.2	55.2	
77.0	44.3	49.5	49.9	48.1	49.9	
79.0	43.9	48.1	52.5	45.9	52.5	
81.0	46.9	48.2	51.4	46.7	51.4	
83.0	47.2	47.4	50.0	47.5	50.0	
85.0	46.8	50.4	50.9	47.0	50.9	
87.0	44.8	47.6	52.4	47.5	52.4	
89.0	45.1	46.5	47.6	46.2	47.6	
91.0	44.7	46.4	48.2	46.4	48.2	
93.0	45.5	49.0	50.4	45.3	50.4	
149.0	46.4	47.1	46.4	45.8	47.1	Card hits stacker front stop
151.0	47.3	50.5	54.5	58.0	58.0	
153.0	49.2	57.4	57.3	53.5	57.4	
155.0	46.6	53.9	53.5	49.2	53.9	
157.0	44.5	50.1	48.6	49.0	50.1	
159.0	45.3	48.5	48.9	50.5	50.5	Card hits stacker back stop
161.0	50.1	48.1	51.0	52.3	52.3	
163.0	51.1	53.7	56.6	54.0	56.6	
165.0	51.2	55.6	54.9	50.4	55.6	
167.0	49.3	52.8	48.6	52.8	52.8	
169.0	46.8	49.7	49.8	48.4	49.8	
171.0	45.6	48.9	51.2	46.2	51.2	
173.0	44.2	48.0	46.1	48.5	48.5	
175.0	42.9	47.6	48.1	47.2	48.1	
177.0	44.0	46.3	47.9	45.4	47.9	
179.0	44.4	46.0	46.5	44.5	46.5	
181.0	43.6	44.6	46.9	44.0	46.9	
OCTAVE AVG NR LEVEL	47.5	48.6	52.2	49.4	NR VALUE 52.2	

Figure 10 Machine printout of digital soundprint from card reader. The intervals from 94 through 148 ms and from 182 through 200 ms, when no significant noise bursts take place, have been omitted. Numerical values are rms dB corrected for NR.

each 2-ms interval. The right-hand column shows the maximum NR value of the octave bands for each 2-ms window. The NR numbers at the bottom show the average rms value in each octave band over the entire 200 ms. If the rms value over one cycle is desired, only the first approximately 160 ms of the signal would be used.

From this printout the sources of noise bursts can be identified. It can be seen that the bursts are primarily from magnets sealing, the leading edge of the card passing under feed rolls, and the card striking the front and back stops in the stacker. The quantitative significance of these bursts relative to the steady noise of the machine can also be established. The steady noise is caused by turning bearings and belts, the drag of the card along the bed plates, etc. Improvements to the machine can also be simulated without changing the hardware. For example the noise burst from the stacker front stop at 150 ms could be artificially attenuated by 5 to 10 dB in the top octave bands. The total cycle rms could then be recalculated to determine if quieting the stop by 5 to 10 dB would be beneficial.

Another use for this approach is in quality control inspection of mechanical devices. Normal acoustical measurements show only the noise from a machine or device as a function of amplitude and frequency. Soundprints of mechanical devices could be much more useful in defining the cause of a change in noise. An increase in levels at all times might indicate a loss of effectiveness in a machine's covers due to poor seals. An increase in the background levels but not the bursts could indicate a noisy motor or bearings. An increase in a burst could indicate an unusual impact in a particular function.

Conclusions

Essentially two procedures are currently used in noise-time analysis: subtraction and the hybrid approach. These techniques are substantially different in equipment requirements, and results obtained from each have unique applications. The major advantages of subtraction are that: 1) Limited equipment is required. The switch-attenuator is simply implemented and, along with an oscilloscope, provides sophisticated noise-time analysis with conventional acoustical instruments. 2) The subtraction approach is particularly useful in simulating machine improvements on a time scale before redesign.

The negative characteristic of subtraction is a subtle fault. Interpretation of the graphs is less obvious, it is difficult to combine the information from two graphs, and effective analysis by this method requires experience.

The advantages of the hybrid system are that: 1) Results are positive and easy to interpret. A detailed picture of the machine cycle is available. 2) Flexibility and analysis depth are possible through computer programming. 3) Detail analysis is simple and obtainable at a level of detail difficult to duplicate with analog techniques. 4) The frequency-time matrix form of the output makes it easy to evaluate combinations of machines and mechanisms. For example, the analysis printouts of two individual mechanisms can be combined element by element to define the effects of two noise sources operating simultaneously.

The basic limitations of the hybrid system are in the tradeoff between the rms circuits and the digital multiplexing. The present hybrid system has been optimized for noise-time analysis and represents a unique solution to the problem in this area. More versatile parallel filter sets are available and can be directly substituted in the system without detracting from its features.

Noise-time analysis techniques are particularly useful in mechanism analysis. Since the date of an earlier report on the subject [4] they have been used extensively in identifying noise sources in experimental mechanisms. The applicability of these techniques is due to two factors: First, many of the noise sources in IBM equipment are serial in nature. This is evident in machine timing diagrams, although integration of rapid cyclic noise by the human ear tends to obscure this fact. The analysis techniques described depend only on some separation in time and are independent of these integration effects. Second, many of the controllable noise sources in mechanisms are impacts that release functionally unnecessary energy. The high frequencies associated with these impacts provide sharply defined transients that lend themselves readily to noise-time analysis.

Noise-time analysis has proved to be a valuable tool for identifying noise sources and their significance. Once the noise sources are identified a major step is accomplished in the process of designing quieter machines.

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