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A New Technique for Dynamic Analysis of Acoustical Noise

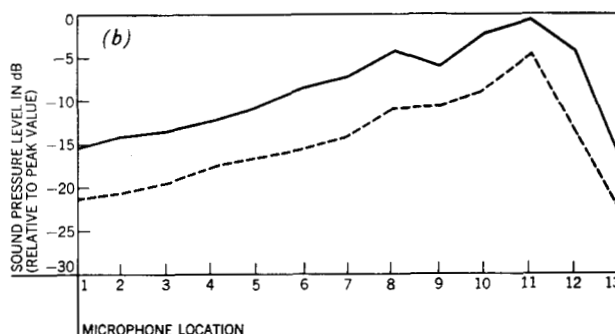
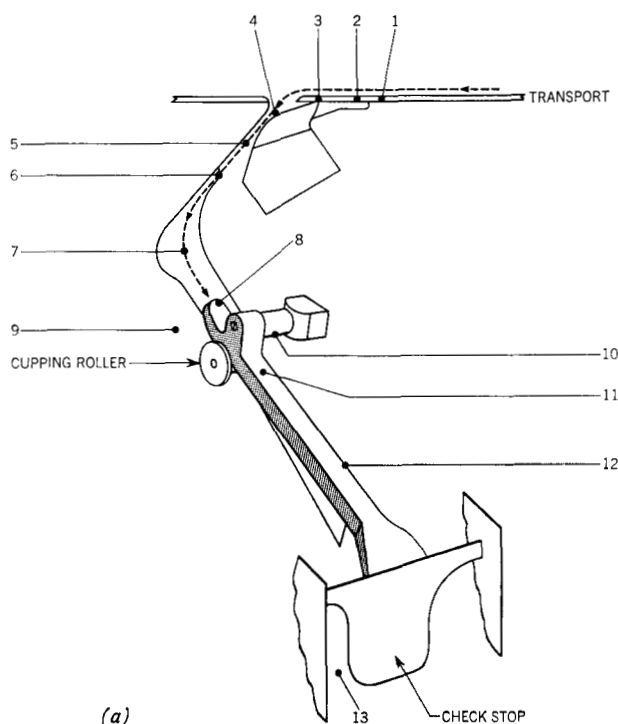
This communication discusses some preliminary work on a new acoustical analysis technique and its application to the detection of noise sources in paper document handling machines. The technique, a time-domain dynamic-analysis method, used in conjunction with the conventional analysis techniques based on frequency and spatial analysis, has permitted the development of design principles for minimizing the output of "paper noise"* from document handling systems. The analyses show that, in general, paper noise can be minimized by maintaining maximum control of all document surfaces throughout the document path. The dynamic analysis system described here is the first part of an effort to develop a method for instantaneous recording of noise levels. When fully developed, the system will permit rapid analysis of many noise problems.

Acoustical analysis

In an attempt to discover and rate the relative importance of paper noise sources in a high-speed document handling machine, the limitations of frequency and spatial analysis techniques became apparent. Frequency analyses of the noise produced in two types of IBM's document stackers (see Appendix) were performed using the conventional instrumentation: microphone, power supply, sound-level meter and filter set, and graphic-level recorder. Sound pressure levels were measured both with and without documents flowing. Although this technique showed paper noise to have a wide bandwidth, it was of little help in locating noise sources.

A spatial analysis technique made use of a microphone fitted with a special probe. The microphone was adjusted to provide a flat response up to and beyond 20,000 cps. Since the probe introduced a known attenuation with respect to frequency, data taken with this technique were compensated for this loss. Measurements of sound

Figure 1 (a) Stacker mechanism for 1210, (b) Wide-band sound-pressure levels at the microphone locations illustrated in (a). Solid line: 44 lb paper; dashed line: 24 lb paper.



* In this note "paper noise" is defined as the airborne acoustical energy radiated from the document surfaces.

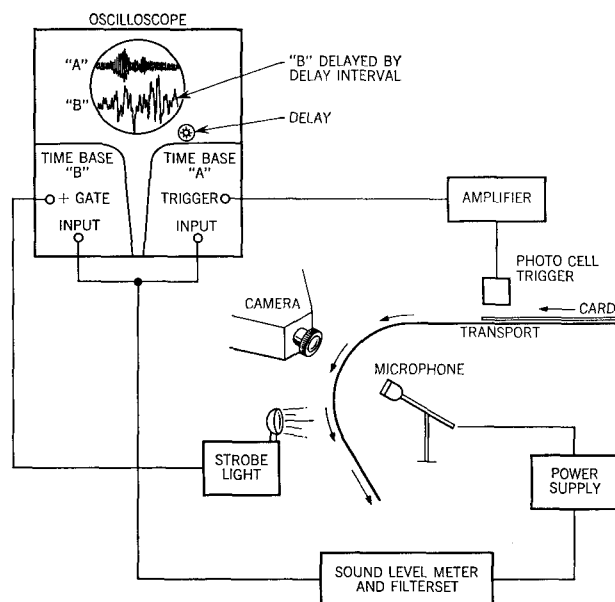


Figure 2 Instrumentation for new time-domain dynamic-analysis technique.

pressure level were made at specific points (Fig. 1a) along the document path. Figure 1b gives typical plots of wide-band noise levels obtained by this method.

Frequency and spatial analysis techniques were somewhat useful in locating noise sources, but they were not adequate. A basic problem with both techniques is that they use a time-averaging readout device. This is often a desirable quality. However, in the machines being investigated here, the stack cycle is not more than 75 msec. The inadequacy of quasi-static techniques to measure noise levels within that cycle is a basic limitation.

A dynamic measuring system was developed to overcome this problem. With this system an oscilloscope displays the instantaneous microphone output, and this output is recorded on film. A digitizer and computer are used to extract and calculate the rms sound pressure level during any desired time increment. When the machine stacking cycle is split into many increments, a highly detailed plot of dynamic noise level versus time or document position can be obtained.

Figure 2 is a diagram of the instrumentation for this system. The microphone is positioned equidistant from the card centerline throughout the stacking cycle. This is done to equalize attenuation with distance, and to equalize time delay for sound waves traveling to the microphone from each part of the document path.

The microphone output is displayed on a dual-beam oscilloscope. The oscilloscope "A" sweep is triggered to begin a display when the document leading edge passes a transport-mounted photocell. By proper choice of photo-

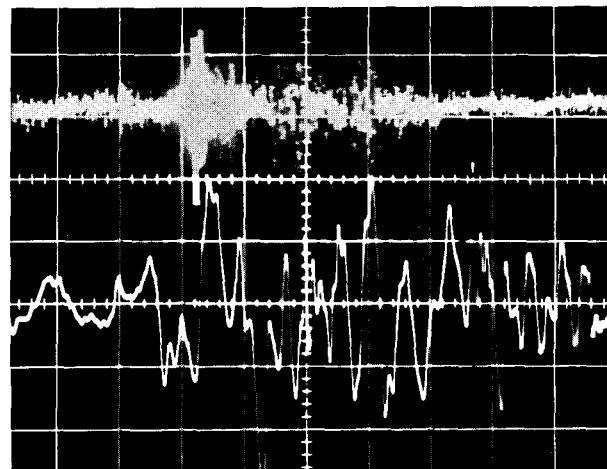
cell location and oscilloscope sweep speed, the noise output for a single complete stacking cycle of time duration T can be displayed on the "A" sweep. The second beam is delayed by the *DELAY* control. This beam sweeps at a rate controlled by the "B" time base, and displays the microphone output for a short time, ΔT . With properly adjusted *DELAY* increments, the "B" sweep presents a series of consecutive end-to-end pictures of instantaneous noise level. The pictures show total stacking cycle energy related to the machine cycle. A brightened portion of the "A" sweep shows the position of ΔT relative to the stacking cycle.

Simultaneously with the photographing of data from the oscilloscope (Fig. 3), pictures of the stacker are taken to show document position. The light source for the document pictures is a stroboscopic light controlled by the "B" sweep "+" gate. Flash occurs at the beginning of ΔT . The product of this analysis technique is a "flip chart" of correlated noise and stroboscopic document pictures covering the entire stack cycle.

The rms data is obtained using a computer program to interpret digitizer analysis of these records. A more detailed description and procedures for using this technique are available.¹

Two additional techniques were used to evaluate causes of paper noise. High-speed motion pictures of documents flowing through noise producing areas identified radiating mechanisms. The shock waves in the documents which produced the significant noise sources were clearly visible. In some cases, mechanism parts were removed to determine their significance. Because of secondary effects on operation, however, this technique had limited value.

Figure 3 Sample oscilloscope trace recorded with instrumentation of Fig. 2.



Evaluation of analysis

Data obtained with the various analysis techniques show three distinct causes of paper noise in the stacker mechanisms tested (IBM 1210 and 1219-1419).

1. Initially, a noise burst is released when the document leading edge is cupped. Highest levels occur when the document is reshaped to enter each roll pair.

2. A second noise burst occurs when the outside trailing edge of the document leaves the paper guide and slaps against the stacker drive cover in the 1210. A similar burst occurs in the 1219-1419 when the trailing edge leaves the first cupping roll pair or stacker rolls.

3. The final burst of noise occurs when the leading edge of the document strikes the check stop.

Data taken on 13 sample stackers indicated that while the absolute values of noise level varied from sample to sample, the same sources of paper noise and their relative importance were identified in each.

Tests were run to determine the effects on noise output of document weight and size, speed and direction changes, and freedom of motion. Although wide-band noise is proportional to document weight, plots like that of Fig. 4 showed that the instantaneous noise produced by each source is not. The cupping operation, which is one of constant displacement, produces noise output independent of weight while the noise output for other operations depends on document energy (mass) and stiffness. Paper noise is also proportional to document size. Cupping-noise peak level is independent of size, but duration (hence, energy) increases with size. Other noise sources are reduced because of reduced energy and better control.

Sudden changes in document velocity contribute to noise which is due to paper rather than system reaction. Accelerometer measurements on the stacker drive cover, for example, showed little excitation because of document slapping impact.

To see how controlling the deceleration of the document would affect noise output, certain modifications to the stacking mechanisms were tried. On one stacker, an adjustment of the document stack-height sense arm allowed increasing the friction between moving and stationary documents, thus spreading deceleration over a longer time. Figure 5 shows the instantaneous noise levels for three positions of the stack arm. A high setting (producing greater friction) is shown to be a significant factor in reducing the noise at the stop.

Another type of deceleration control involved replacing rubber-pad type check stops with short, stiff bristles. Here, much of the document energy was dissipated over a longer distance in deflecting the bristles. This change essentially eliminated noise generated at the stop. Both of

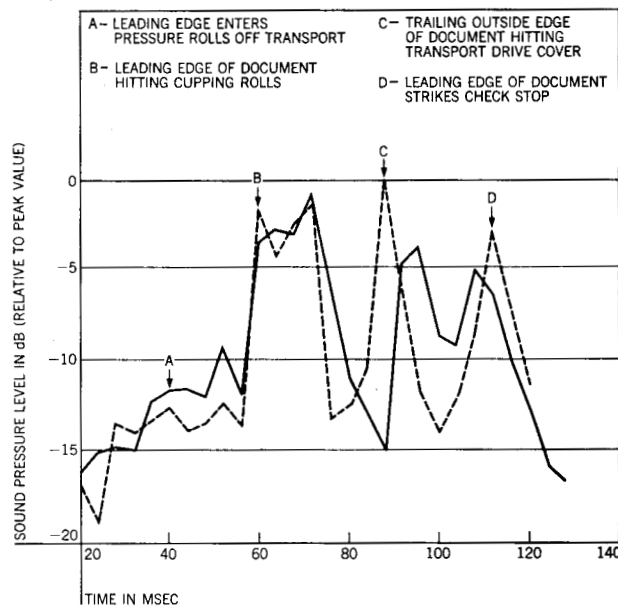


Figure 4 Instantaneous sound pressure level from 1210 stacker determined from computer processing of data obtained with instrumentation of Fig. 2. Solid line: 44 lb paper; dashed line: 20 lb paper.

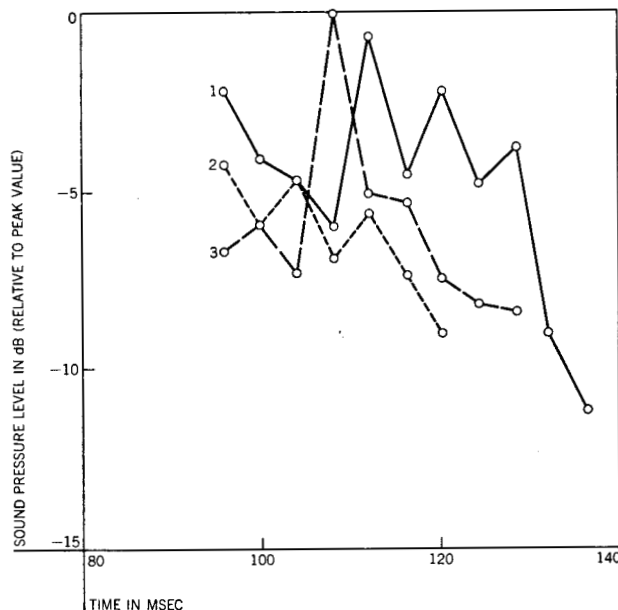


Figure 5 Instantaneous sound pressure level from 1210 stacker with 44 lb paper. Curves show effect of different stack-height sense arm settings: 1: low, 2: high, 3: normal.

these experiments showed that holding deceleration below the value that produces shock wave reaction in the document will reduce the creation of paper noise.

Modifications were tried which would produce slower changes in document direction. Document cupping noise was reduced by replacing the cupping rolls with flat rolls

and cupping the document gradually in the guide chute. The guide chute was given various shapes: curved bend; low, straight bend; and high, straight bend. Noise output was least for the curved bend and greatest for the high, straight bend. This illustrated the general rule that noise will be reduced if sudden, discontinuous changes in document direction are avoided.

When sudden changes of document direction are essential, however, means should be provided for restricting the document's freedom of motion. In an experiment to illustrate this point, an extension to the guide chute prevented the document's trailing edge from slapping the mechanism as it passed through the bend on its way to the stack, thus eliminating this noise source. A properly designed guide directs the document without inducing unwanted transverse or lateral document vibrations. It also prevents uncontrolled document motions which result from paper stiffness.

Conclusions

Accurate identification of noise sources in high-speed mechanisms like those of document handling machines demands the use of dynamic analysis techniques. To meet this requirement a new technique was devised. It represents the first step toward a measurement system that will permit instantaneous recording of dynamic noise levels.

During an application of this analysis method, design principles were developed for minimizing paper noise in document handling machines.

A stacker that minimizes paper noise must:

- (a) Eliminate discontinuous direction changes that occur in the document path path by minimizing the magnitude of direction changes and reducing their rate by spreading them out in time.
- (b) Reduce the rate of energy transfer to and from the document by controlling document acceleration and deceleration.
- (c) Maintain maximum control of the document surfaces throughout the document path with effective guides.

The rate at which operations occur, not the operations themselves, cause paper noise. If operations on the document occur so that the entire document can "follow" changes in the leading edge, paper noise will be controlled. If not, there is a limiting threshold above which noise-producing shock waves develop in the document.

Changing an existing mechanism to control paper noise will in some cases actually improve the function of the mechanism. However, careful investigation is required to assure that function is maintained.

Appendix—The document stacking mechanism

The IBM 1210 and 1219-1419 stackers, which differ in mechanical detail, are variations of a platform stacker concept. In each stacker, the document is forced off the transport into a guided cylindrical bend by deflector chute blades. The document is then momentarily given longitudinal rigidity by transverse cupping. A short period of free flight follows the cupping operation and finally the document motion is arrested by check stops. At this point the document leading edge is aligned above previously stacked documents, which are resting on a platform. Aided by a deflector spring, the document settles onto the stack. Stack height is maintained by a sense arm and an air valve, which control platform elevation.

The transport speeds of the 1210 and 1219-1419 stackers are 216 and 270 ips, respectively. In the 1210, the document passes between a spool-shaped cupping roll traveling at transport velocity and a lever arm that holds the document against the roll to accomplish the transverse cupping required for stacking. In the 1219-1419, the document is cupped in two stages. The leading edge first passes between a pair of stacker rolls operating at transport speed where it is partially cupped. Then it passes between a pair of decelerator rolls operating at 216 ips where it receives the final cupping action. The rapid shape changes that occur in both machines during cupping of the leading edge and release of the trailing edge from the cupping rolls are prime contributors to the release of acoustical energy.

Acknowledgments

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Reference

1. R. H. Peterson and R. L. Hoffman, "Noise Time Analysis," IBM Technical Report, TR07.071.

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