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Effect of Vibration on Retention Characteristics of Screen Acquisition Systems

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The design of surface tension propellant acquisition systems using fine-mesh screen must take into account all factors that influence the pressure differential between liquid and gas regions interfacing at the screen. One of those factors is spacecraft vibration. Analytical models to predict the effects of vibration have been developed. A test program to verify the analytical models and allow a comparative evaluation of the parameters influencing the response to vibration was performed. Screen specimens were tested under conditions simulating the operation of an acquisition system, with the effects of such parameters as screen orientation and configuration, screen support method, screen mesh, liquid flow, and liquid properties considered. An analytical model, based on empirical coefficients, was most successful in correlating the effects of vibration.

Introduction

SURFACE tension propellant acquistion systems are now in use and under development for numerous spacecraft applications. Most of these surface tension devices make use of fine-mesh screen to provide a liquid flow path and prevent gas from entering the tank outlet. Their operation uses the pressure differential established at the gas-liquid interface within the screen pore by virtue of capillary action; this mechanism will be referred to as the capillary pressure or retention capability of the screen. Sufficient capillary pressure is generated to just balance any adverse pressure differential (i.e., that tending to drive gas through the screen pores into the liquid) up to the maximum retention capability, which is determined by the screen pore size and the liquid surface tension. Design of these acquisition devices requires that all contributions to the adverse pressure differential acting on the screen be taken into account.

Vehicle accelerations and propellant flow are the typical sources of the adverse pressure differential acting on the screen. Vibration of the spacecraft can also contribute to the pressure differential. The launch vibrational environment is usually the most severe, but a spacecraft can also experience vibration from the firing of attitude control or orbit adjust engines, or even from crew movement.

Some prior test programs have demonstrated that vibration can influence the performance of surface tension acquisition systems. Models of complete systems (tank plus surface tension device) have been tested to determine the influence of vibration on expulsion capability.[1-3] Discrete screen elements were tested under other test programs.[4,5] These programs were limited in scope and provided only a gross assessment of the influence of vibration. This program continued the investigation, making an in-depth study of the many factors that can influence the response of the screen to vibration. This paper summarizes the results of the investigation.[6]

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Vibrational Effects Analysis

The objective of the vibration analysis was to predict if the screen maintains its retention capability or loses it (screen breakdown) in an applied vibration environment. Usually, the input vibration at the tank supports is specified on the basis of the transmission from its source. The amplitude of this vibration, of either random or sinusoidal form, is specified as a function of frequency. Proven analytical methods can predict the transmission of the vibration to the attach points of the surface tension device and through the surface tension device structure. The vibration is then transmitted to the screen. Factors such as the structural characteristics of the screen and its support method and the coupling of the retained liquid mass influence the dynamic response of the screen. A result of the transmission of the vibration is a variation in the pressure within the liquid retained by the screen. When the vibration-induced pressure differential, superimposed on the steady pressure differential from other sources, acts on the screen, retention of the liquid is either maintained or lost. At some point on the surface tension device, the screen will be most susceptible to the combined effects of the steady pressure differential and the pressure differential due to vibration; so the analysis can be directed toward only that area of the device.

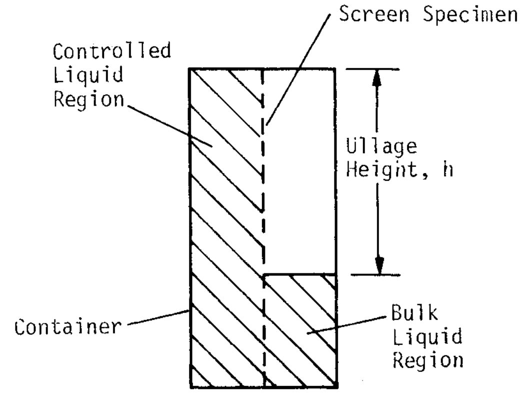

Fig. 1 Test model configuration.

Table 1 Screen specimens

Screen mesh-weave	Bonded to perforated plate	Supported by perforated plate	Unsupported	Pleated	Internal rib	External rib
325 x 2300 Dutch Twill	6	7	1, 2, 3, 4, 5[a]	8	9	10, 27
200 x 1400 Dutch Twill			20			11
165 x 800 Dutch Twill	18		21			12
165 x 800 Plain Dutch		19[a]	22[a]		23[a]	13[a]
80 x 700 Dutch Twill				26		14
50 x 250 Plain Dutch						15
850 x 155 Robusta			24,[a] 25			16
200 x 200 Square						17

[a] Screen weave oriented with the warp in the long direction; all others have the weave oriented with warp in the short direction.

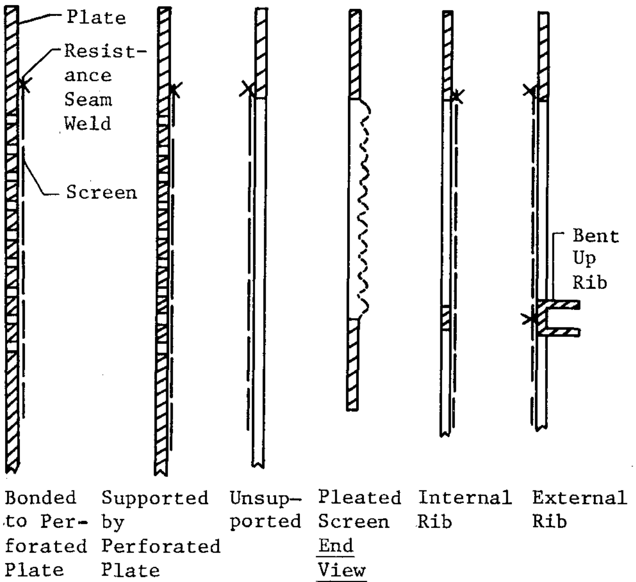

Fig. 2 Screen mounting configuration (controlled liquid region to the left of the specimen; bulk region on the right).

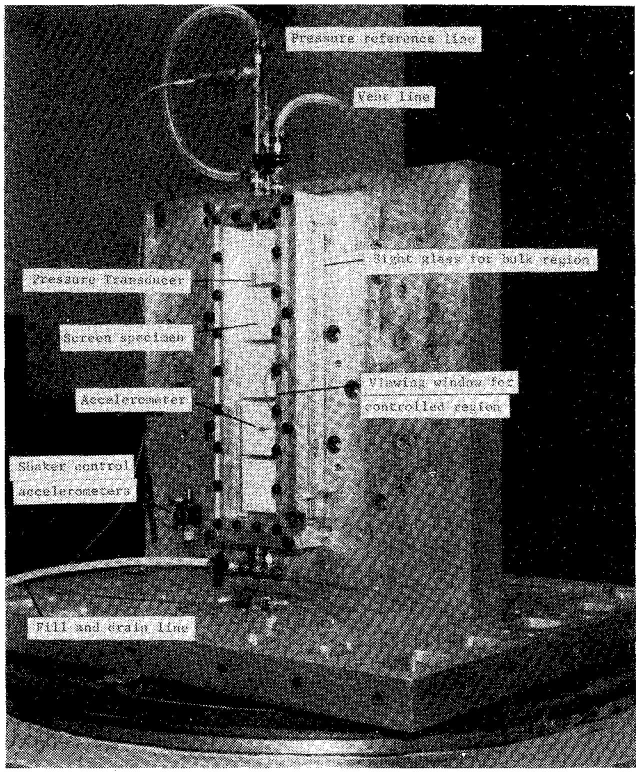

Fig. 3 Model mounted on shaker.

Two approaches to the analysis of the response of the screen to vibration were taken. One, a screen dynamics approach, was based on the detailed aspects of the screen response, as described above. An analog consisting of the screen compliance, liquid mass, and liquid flow resistance was constructed. Owing to the nonlinear nature of the screen response, discovered during the testing, the success in verifying this model was limited. Further details can be found in Ref. 6.

The other approach, referred to as the hydrostatic model, is an empirical method of predicting the effect of vibration on the screen retention. Previous studies have found that this model can predict the effect of vibration under certain conditions.[1-5] The assumption is that the effect of vibration is hydrostatic in nature. According to the model, a pressure differential (ΔP_v) between the liquid on one side of the screen and the gas on the other, due to the vibration, has the form

$$\Delta P_v = K\rho g h$$

Thereby the pressure differential is proportional to the liquid density (ρ), the acceleration due to the vibration (g), and the height of the liquid being retained by the screen (h). The coefficient K accounts for all the other factors influencing the vibration response, such as the characteristics of the input vibration, screen device geometry, and screen support method. Since all factors are lumped into a single coefficient, it must be empirically determined. To predict the occurrence of screen breakdown, the pressure differential due to vibration is added to all other pressure differentials acting on the screen, and the total pressure differential is compared to the maximum retention capability of the screen.

Experimental Investigation

The experimental investigation reported herein was performed to determine the effects of vibration on the retention capability of fine-mesh screens. The experimental program was devised to achieve this objective in two ways. First, the tests provided data for the evaluation of the analytical models referred to in the previous section. In addition, the tests were structured so that direct comparisons between various tests could be made, with only one variable at a time considered, permitting the influence of that variable to be determined.

Approach

Vibration was applied to screen specimens, and the conditions under which screen breakdown occurred were established. The test model consisted of a screen specimen, with its actual support structure, mounted to a rigid container, and the vibration was applied to the container. A flat rectangular screen specimen is typical of most surface tension devices and provides a geometry that can be readily analyzed. Only a representative portion of a surface tension device was simulated, with the screen specimen forming the controlled

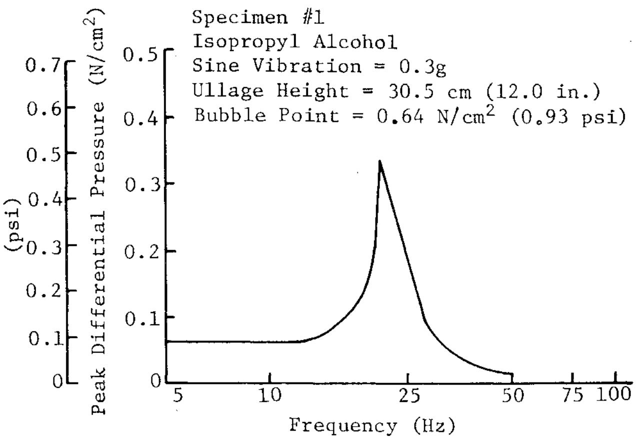

Fig. 4 Variation of differential pressure with frequency.

region of the device, which retains liquid and excludes gas. The other half of the model simulates the bulk region of the tank, shown in cross-section in Fig. 1.

The basic configuration of the test model being defined, there are a number of parameters that can influence the response of the screen to an applied vibration. The parameters considered are as follows:

1. Test Liquids

Three test liquids were selected: isopropyl alcohol, Freon 113, and Freon 11. Their varied densitites, viscosities, and vapor pressures permit the influence of liquid properties to be considered.

2. Screen Mesh

Eight screen meshes, listed in Table 1, were selected, covering the full range of fine-mesh screens used for surface tension devices.

3. Screen Mounting

Six different methods of supporting the screens were selected (Fig. 2 and Table 1). All are proven techniques, based on fabricated prototype and flight surface tension devices. The screen weave can have two orientations with respect to the mounting structure.

4. Configuration

Two configurations for the controlled liquid region were considered. The first has the controlled region formed by a screen specimen and the other sides are the container; and the second has the controlled region formed by two parallel screen specimens and the other sides are the container. Six possible orientations of the vibration and 1*g* with respect to the screen specimen were evaluated.

5. Applied Vibration

Two forms of vibration were used: sine and random. Sine vibration was applied over a range of frequencies and at a peak amplitude. Random vibration was applied on the basis of a spectrum of the power spectral density vs frequency. The shape of the spectrum was held constant, while the values of the power were varied, changing the applied rms vibration *g* level.

Test Apparatus

The test system consisted of an electrodynamic shaker, the surface tension device model, and the associated plumbing required to operate the model. Aluminum frames formed the bulk and controlled liquid regions of the model, each having dimensions of 39.4 cm (15.5 in.) long, 8.9 cm (3.5 in.) wide, and 2.4 cm (0.95 in.) thick. A total of 27 screen specimens, as identified by specimen number in Table 1, were fabricated and tested. A plastic window on the controlled liquid region

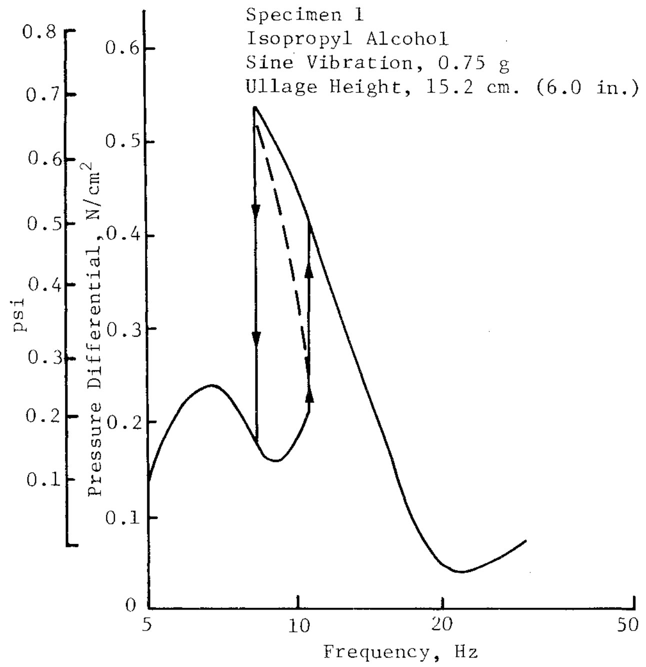

Fig. 5 "Softening spring" response.

side of the model permitted direct viewing of screen breakdown.

The model was either bolted directly to the faceplate of the shaker or to a mounting plate perpendicular to the faceplate. By orienting the shaker axis either vertically or horizontally, the six model orientations were obtained. The orientation in which the vibration and 1*g* acted parallel to the length of the screen specimen is shown in Fig. 3.

A miniature pressure transducer was mounted in a tube and could be positioned along the screen surface in the controlled region. This placed the diaphragm of the transducer directly at the point of interest. By connecting the transducer differentially and removing dc pressure components, it directly measured the pressure differential due to the vibration. A miniature accelerometer was mounted at various locations on the screen specimen to record the local acceleration.

Test Program

A test matrix was established considering the most interesting combinations of the many variables discussed above and each of the 27 screen specimens. A total of 551 vibration tests were performed.

The test procedure was to first fill the controlled region of the model, purging all gas, and the bulk region was filled to the desired level. For a sine sweep test the amplitude of the vibration was held constant while the frequency was varied. Beginning at 5 Hz, the frequency was increased at a fixed rate to an upper limit (100 to 500 Hz) and then decreased back to 5 Hz. Sine dwell tests were performed by holding the vibration amplitude and frequency constant while varying the liquid level in the bulk region.

Random vibration tests were similar to the sine dwell tests. For a fixed random vibration spectrum and overall *g* rms level, the liquid level in the bulk region was varied to find the point of screen breakdown.

As the liquid level in the bulk region was lowered, the liquid column within the controlled region that was being supported by the screen was increased. For the model orientation shown in Fig. 3, this column height determined the hydrostatic pressure differential acting on the screen, being the greatest at the pores at the top of the specimen. Lowering the bulk liquid level, therefore, brought the screen closer to its maximum retention capability.

Test Results

Discussion of Results

The test matrix was set up so that the influence of various factors on the response of the screen to vibration could be investigated. Testing progressed from the simplest model configuration, using the special screen specimens, with the other variables gradually introduced. In the following paragraphs the conclusions drawn from the evaluation of the test data are discussed.

1. Characteristics of Screen Response

The data obtained with the pressure transducer during the sine vibration tests provided information on the characteristics of the screen specimen response to vibration. The pressure waveform measured for the nonrigid screen specimens had a definite positive bias, where positive is defined to mean that the ullage pressure in the bulk region is greater than the pressure of the liquid in the controlled region. The positive peak of the pressure differential waveform was much greater than the negative peak. In contrast, the pressure differential for the rigid specimens (those with the screen bonded to the perforated plate) had equal-amplitude positive and negative peak pressures over the full frequency range. Movement of the screen, when possible, relieved the negative pressure differentials.

At low frequencies (approximately 5 Hz) the pressure differential was sinusoidal in form and was in phase with the applied sine vibration. The peak amplitude of the pressure differential was the hydrostatic pressure based on the peak acceleration at the same point in time. As the harmonic frequency of the model was approached, the amplitude of the pressure differential increased, reaching a maximum at the harmonic. At the harmonic frequency the pressure differential waveform was a series of positive peaks (excepting the rigid specimens) that lagged the applied acceleration by a phase angle of 90 deg. At frequencies greater than the harmonic, the pressure differential amplitude decreased, the phase lag increased to 180 deg, and the waveform was again sinusoidal. This phase lag of the pressure differential is typical of the phasing of the input and output of a classical spring-mass system.

A plot of the typical variation of the positive peak pressure differential with frequency is shown in Fig. 4. The higher modes were usually much less significant than the first harmonic. At low vibration amplitudes the curve in Fig. 4 would be followed regardless of whether the frequency was increased or decreased.

At larger accelerations the hysteresis effect shown in Fig. 5 was noted. One curve was obtained as frequency increased, and another as it decreased, indicating that the peak leans over toward lower frequencies. This type of response is typical of a "softening spring" that becomes less stiff as it is displaced. This nonlinearity must be due to the liquid interface within the screen pores, indicating a significant contribution to the screen stiffness. A single gas bubble has been shown to have this softening spring response in a sinusoidally varying pressure field.[7]

The location of the pressure transducer could be varied along the length of the model. With the model mounted as shown in Fig. 3, the pressure differential due to vibration was a maximum at the top of the model (which is the top of the screen), as shown by Fig. 6. The amount of liquid mass associated with the system response was maximum at the top of the model, producing the maximum pressure differential.

2. Screen Breakdown

The severity of screen breakdown covered a wide range, which was best demonstrated by the random vibration tests. As the hydrostatic pressure differential acting on the screen was increased, while holding the g rms level constant, screen breakdown was first noted as very small bubbles, on the order of 0.2 mm (0.01 in.) diameter, passing through the screen. As

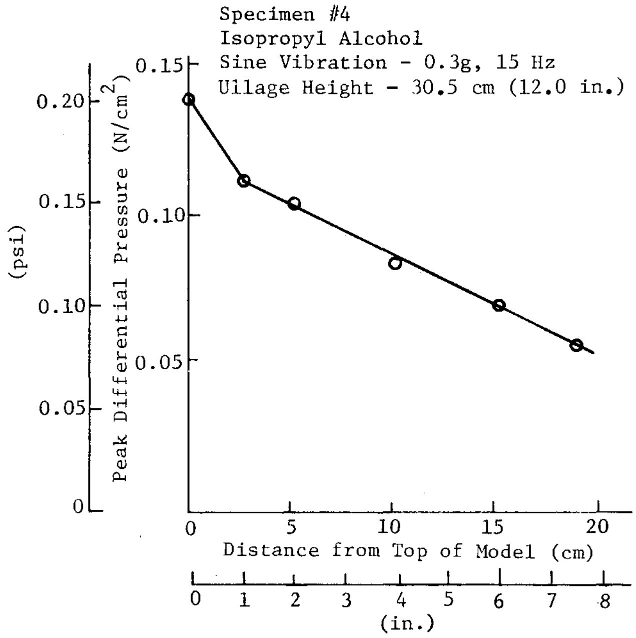

Fig. 6 Variation of pressure differential with position in liquid.

the hydrostatic pressure differential continued to increase, the size and quantity of the bubbles increased, reaching the point at which a definite accumulation of gas could be observed and the breakdown was significant. At larger hydrostatic pressure differentials, excessive break down could be observed when large quantities of gas would pass through the screen and quickly fill the controlled liquid region. The nature of random vibration, with the acceleration peaks distributed over a wide range of frequencies, allowed the gradual transition in the severity of the screen breakdown. The span in hydrostatic pressure differential required to go from the first indication of screen breakdown to excessive breakdown was equivalent to 18% of the maximum retention capability of the screen.

With sine vibration screen breakdown was more distinct, with the first indication of breakdown being of significant severity, rather than the slight, tiny bubbles. The harmonic interaction of the sine vibration with the model caused breakdown to begin with only small changes in frequency or hydrostatic pressure.

With both sine and random vibration, screen breakdown continued as long as the condition that caused breakdown was maintained. The screen regained its retention capability after the conditions were changed sufficiently to allow breakdown to cease.

The sine dwell tests demonstrated that the peak positive pressure differential due to the vibration, reducing the liquid pressure with respect to the bulk ullage, caused the screen breakdown. The negative pressure differential was much lower in amplitude with the loosely supported screens. When the hydrostatic pressure differential was added to the peak positive pressure differential due to vibration measured at the point of screen breakdown, the sum was equal to the maximum pressure retention capability of the screen. At the frequencies involved, the gas-liquid interface within the screen pore was responding to the positive peaks of the pressure differential due to vibration. No time-dependent factors influencing the interface response were noted.

It was found that the screen support method influenced where on the screen specimen the breakdown occurred. With the model oriented as shown in Fig. 3, the hydrostatic pressure differential was a maximum at the top of the screen, and so was the measured pressure differential due to vibration (Fig. 6); so it would be expected that the screen breakdown would first be detected at the top pores of the screen specimen. This was the case for the tests with the more rigidly

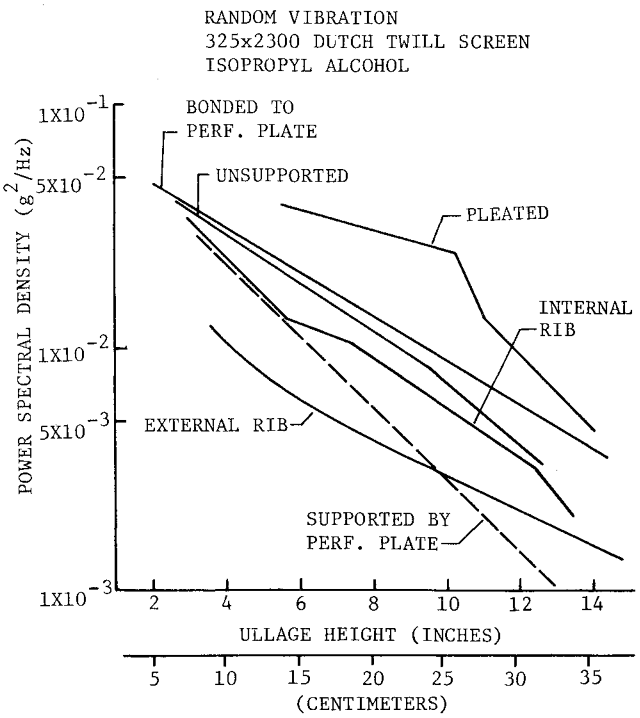

Fig. 7 Influence of screen support method on response to vibration.

supported screens (bonded and pleated specimens) and for the coarser, more rigid screen specimens.

However, the loosely supported specimens with the finer, flimsy screens would breakdown in various locations on the portion of the screen that was exposed to the ullage of the bulk region. Only small patches of screen would breakdown, and the location would shift with frequency and hydrostatic pressure differential. Observable localized flutter of the screen caused this manner of screen breakdown. Small portions of the screen could oscillate, independent of the net oscillation of the screen panel. This increased the local pressure differential, causing the screen breakdown.

3. Effect of Weave Orientation

With the exception of the square weave screen, the screens of interest have wires that are different in number, configuration, and diameter in the opposite directions. It would be expected that this would give the screen nonuniform properties influencing its deflection and response.

Specimens that were identical, except that they had opposite screen orientations, were tested. Comparing the results, in particular the frequency and amplitude of the first harmonic, it was found that the response was essentially identical. It was concluded that the influence of the weave orientation was negligible.

4. Effect of Model Orientation

A single screen specimen was tested in various orientations. The vibration acted either parallel to the length of the specimen, parallel to its width, or perpendicular to the specimen. The orientation of the model with respect to 1*g* either eliminated the influence of the hydrostatic pressure differential or permitted the hydrostatic pressure differential to be varied by varying the bulk liquid height. A total of six orientations were investigated.

It was found that the effect of the vibration was directly proportional to the length of the liquid column in the controlled region, parallel to the direction of the vibration. This proportionality could be seen in the magnitude of the pressure differential at low frequencies, where there was no amplification. The presence of bulk liquid on the other side of the screen made the column height approximately equal to the column of liquid that was being retained by the screen.

Therefore the screen was least sensitive to vibration perpendicular to the screen, where the column height was equal to the 2.4-cm (0.95-in.) controlled region thickness. The screen was most sensitive when the vibration was parallel to the 39.4-cm (15.5-in.) length of the screen specimen.

5. Effect of Screen Support Method

Six screen specimens, each with a different support method but the same 325 × 2300 screen, were tested. Each specimen was tested under identical conditions, using random vibration. The *g* rms vibration level was varied, and the point of significant screen breakdown was established at each level. The results are plotted as a function of the ullage height in the bulk region at which breakdown occurred and the power spectral density of the random vibration (the spectrum had a constant power from 8 to 500 Hz) in Fig. 7.

These curves show a definite effect due to the screen support method. The more rigid "pleated" and "bonded" specimens were the least sensitive to vibration, while the "external rib" and "supported by perforated plate" were the most sensitive. It is hypothesized that the support method influences the sensitivity of the screen to vibration in two ways. One factor is the bulk displacement of the screen that occurs when the entire screen panel or the individual windows of the specimen displace in response to the vibration. Bulk displacement of the screen permits the controlled liquid volume to increase, relieving the pressure differential caused by the vibration. Displacement of the screen toward the controlled liquid side of the model acts to limit the reduction of the pressure in that region, which is tending to cause screen breakdown.

The second factor influencing sensitivity is the localized displacement of only a small area of the screen. The support method and the fabrication techniques permit the localized displacement to occur. It has already been shown that localized displacement increased the sensitivity of the screen to vibration. On a relative basis, the hypothesis also considers the influence of the localized screen displacement to be more significant than the influence of the bulk displacement.

On the basis of this hypothesis, the relative ranking of the support methods as a function of their vibration sensitivity (from least to most sensitive), is established from the significance of the two factors:

Pleated—bulk displacement (the pleats ran the length of the specimen) and no localized effects.

Bonded—very little bulk displacement and no localized effects.

Unsupported—bulk displacement and some localized effects.

Internal rib—displacement toward controlled region limited by ribs and some localized effects.

Supported by perforated plate—no displacement toward controlled region and some localized effects.

External rib—limited displacement toward controlled region and pronounced localized effects.

These conclusions were substantiated by comparing the degree of screen breakdown and the peak pressure differential amplitudes from identical sine sweep tests of the same set of specimens plus tests with the other screen meshes.

6. Effect of Screen Mesh

Using a common support method (external rib), each of the screen meshes were tested. Specimens of five of the screen meshes using the "unsupported" support method were also tested. The screens differ in their maximum retention capabilities and the stiffness of the wire mesh.

By comparing the peak pressure differentials and the severity of breakdown during sine sweep tests, the relative ranking of the sensitivity of the screens to vibration was established. The ranking was found to be in the same order as the maximum retention capability of the screens, with one exception. The 325×2300 screen, which had a maximum retention capability 50% greater than the next coarser screen, the 200×1400, was more sensitive to vibration than the 200×1400 screen. This was probably due to the influence of the localized effects to which the 325×2300 was more susceptible.

7. Effect of Liquid Flow

Certain vibration tests that were performed under static conditions were repeated under flow conditions. Outflow was simulated using a flow loop. Liquid was pumped from the reservoir into the bulk region of the model through the screen, expelled out the top of the model from the controlled region, and returned to the reservoir. The bulk liquid level was held constant, keeping the hydrostatic pressure differential constant, and low flow rates were used so that the pressure differentials due to flow did not dominate.

When tests under flow and nonflow conditions were compared, the response was essentially the same when the screen flow area was large (full-length specimens and dual-element model). Flow tests with specimens that had a smaller flow area yielded harmonics with a lower amplitude and higher frequency than the nonflow tests. These tests demonstrated that liquid flow may not pose the worst-case condition in a vibration environment and may in fact make the screen less sensitive to the vibration.

8. Effect of Liquid Subcooling

Identical tests were performed using Freon 113 and Freon 11 to evaluate the effect of liquid subcooling. These liquids have similar densities and surface tensions, but the Freon 11 was subcooled 8°C (15°F) and the Freon 113 was subcooled 32°C (58°F) at the test conditions [approximately 20°C (68°F) and 12 N/cm^2 (17 psia)].

Differences in response would only be expected when screen breakdown occurred and allowed gas to be present on both sides of the screen. Under like test conditions the response of the screen was the same with both test fluids (the performance was actually better with Freon 11 in one case), indicating no significant influence of liquid subcooling.

9. Screen Structural Integrity

The retention capability of the screen specimens was measured, using the standard bench test, before and after the vibration tests. One of the specimens, the pleated 325×2300 screen (specimen 8) had a retention capability after testing that was only half its initial retention capability. The pleats were fairly sharp and ran the length of the specimen, which permitted considerable flexing. Owing to these factors and the amount of vibration the specimen experienced, the degradation is not surprising.

None of the other screen specimens experienced any degradation in their retention capability. One of the screen specimens that had a single 7.6-cm (3.0-in.) square opening experienced the most vibration. Sine vibration of up to 5.0 g and random vibration up to 3.0 g rms was applied, with the screen experiencing about 20 h of vibration.

Data Correlation

It was found that the hydrostatic model can successfully predict the pressure differential due to sine vibration at low frequencies when there is little or no influence of the system harmonics. The coefficient K is equal to 1; the acceleration is the peak amplitude of the vibration; and the height is that of the column of liquid being supported by the screen, parallel to the direction of the vibration. The peak positive pressure differential due to vibration can be predicted. However the model has no way of predicting the amplification that occurs near the harmonic frequencies. If the amplification was known or assumed, it would be input as the coefficient K to make the prediction of the pressure differential.

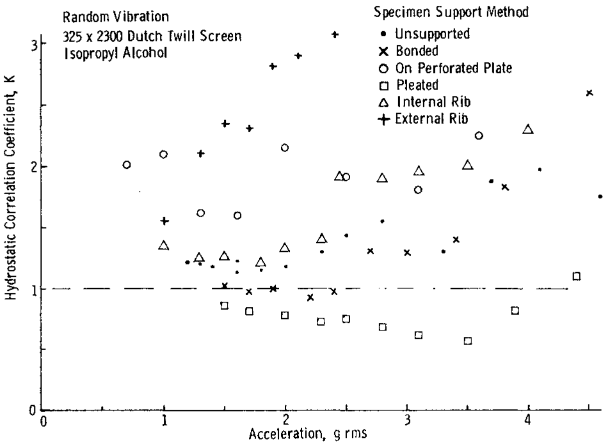

Fig. 8 Data correlation, single-element model.

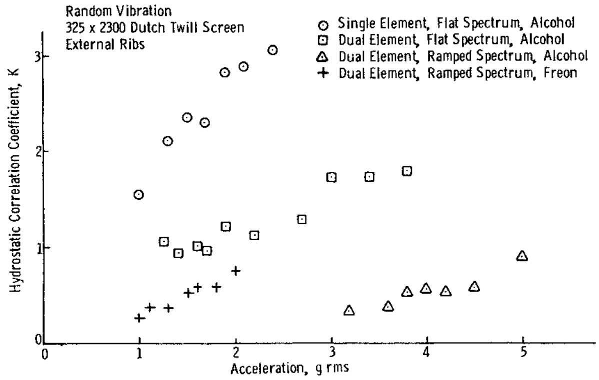

Fig. 9 Data correlation, dual-element model.

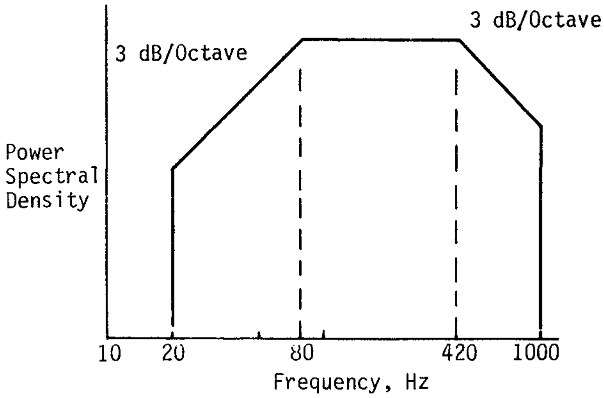

Fig. 10 Random vibration spectrum.

The application of the hydrostatic model for random vibration is similar. The coefficient K must be established from tests with a similar configuration and vibration spectrum or by scaling test data to the desired conditions.

The random vibration data evaluation was performed on the basis of the following pressure balance at the point of screen breakdown:

$$\Delta P_c = \Delta P_v + \Delta P_h$$

where ΔP_c is the maximum retention capability of the screen, ΔP_v is the pressure differential due to vibration, and ΔP_h is the retained liquid pressure head. The value of ΔP_c was measured, and the value of ΔP_h can be calculated from the liquid density and the liquid column height; so the value of ΔP_v can be calculated (this value is a positive rms pressure differential that could not be measured by the pressure transducer). Then using the hydrostatic model equality, the remaining unknown K can be calculated. The random vibration data collected during the test program were reduced in this manner. All of these tests were performed with the model oriented as shown in Fig. 3.

The influence of the structural support method on the value of K, plotted as a function of the g rms level of the vibration, is shown in Fig. 8. The more sensitive the screen specimen was to vibration, owing to the support method, the larger the value of K. The K value for each support method indicates the same relative sensitivity discussed previously. The data appear to indicate that K becomes constant, with values at or near 1, as the acceleration approaches zero and diverges at higher accelerations. The divergence may indicate a nonlinear influence of the value of h, which represents the liquid mass responding to the vibration in the hydrostatic model. Since each data point indicated where screen breakdown occurred, the value of h decreased with increasing acceleration. When h was small, the bulk region was almost full and must have contributed to the liquid mass responding to the vibration.

The results of another series of tests are shown in Fig. 9, in which the effects of dual screen elements, vibration spectrum, and liquid properties were evaluated. The results for the "external rib" specimen (Fig. 8) are repeated in Fig. 9 and identified as the results for a single element. With the model in the dual-element configuration, using two "external rib" specimens mounted parallel to each other, those tests were repeated. The K values for the dual-element model are one-half those of the single-element model. The dual-element model had twice as much screen area, but it also had a controlled region that was only one-half as thick. Either or both of those factors may have caused the reduction in the value of K.

The previous tests, which were performed using a flat spectrum (constant power spectral density from 8 to 500 hz), were repeated with a ramped spectrum (Fig. 10) more typical of an actual spacecraft vibration environment. With this new spectrum the values of K were reduced by about 0.6 the values for the flat spectrum. For a given value of g rms, the ratio of the power spectral densities of the two spectra was found to be about 0.6 on the basis of an estimate of the harmonic frequency of the specimen. Therefore, the change in the value of K can be accounted for by the change in the spectrum.

The same test series, with the ramped spectrum and dual-element model, was repeated, but Freon 113 was used as the test liquid instead of isopropyl alcohol. Comparing the results, the two curves have the same form, and the average value for K was unchanged. The Freon has a lower surface tension, requiring the data points to be obtained at lower accelerations. Freon has a density twice that of the alcohol; so the hydrostatic model must properly account for the liquid density. The alcohol has a viscosity more than three times that of the Freon, but no influence of viscous effects was obvious.

These tests demonstrate that the simple hydrostatic model is capable of predicting the pressure differential due to random vibration. Before it can be used, however, adequate test data must be available so that the proper values for K can be selected. This single coefficient must account for the influence of the vibration spectrum, the screen mounting technique, and the geometry of the controlled liquid region. It has been shown that the effects of the vibration level, liquid column height, and liquid properties can be accounted for by the model. The hydrostatic model provides a means of scaling tests of a surface tension device component, performed with referee liquids, to the actual full-scale device.

Conclusions

This study has investigated the basic phenomena of the effects of vibration on the liquid retention capability of fine-mesh screens. The problem of the response of a screen to vibration was evaluated analytically. A test program considering a large number of variables that influence screen response was conducted. Data were acquired and analyzed from 551 individual vibration tests.

Measurements of the pressure differential due to vibration gave a basic understanding of its amplitude, waveform, and characteristics. A key factor in the screen response is the amplification of the vibrational pressure due to harmonics of the screen-liquid system. It was found that the retention capability is influenced by the positive peak pressure differential (lowering the liquid pressure with respect to the gas on the other side of the screen) due to vibration.

The effect of surface tension device orientation was found to be proportional to the length of the liquid column, supported by the screen, parallel to the vibration axis. The orientation of the screen weave and liquid subcooling had no noticeable effect. The screen support method significantly affects the screen response, with the bulk screen displacement and localized screen oscillation being important factors. Liquid flow tended to decrease the sensitivity to vibration, in comparison to the static case.

Attempts to analyze the detailed response of the screen were hindered by the nonlinear response and localized effects that were discovered. A simple hydrostatic model was shown to be capable of predicting the effects of vibration, if adequate test data are available.

The investigation of the effects of vibration on screen is not complete. Additional analysis and testing is recommended to further explore the basic phenomena and to further develop the hydrostatic model.

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