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AN EXAMINATION OF RIDE PROBLEMS OF THE 6500-GALLON LIQUID CARBON MONOXIDE TRAILER

A REPORT TO:

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INTRODUCTION

Process Engineering, Inc. and Air Products personnel have expressed concern with regard to excessive ride vibration of the 6500-gallon liquid carbon monoxide trailer in highway service. At the request of Process Engineering, HSRI personnel have conducted a brief theoretical examination into the problem. This document is intended to report on that activity and its findings.

It should be noted that at no time have HSRI personnel had the opportunity to see the subject vehicle or to examine it either in the laboratory or on the road. Consequently, it is necessary that all calculations and conclusions reported upon herein derive from estimates of the pertinent parameters involved and should be viewed in that light.

The remaining two sections of this document report upon the analytical activity and the resultant conclusions and recommendations, respectively.

ANALYSIS

Ride disturbances of motor vehicles derive their impetus, in virtually all cases, from the contact forces at the tire-road interface which are transmitted to the sprung mass via tire and suspension systems. Also, they tend to show a magnitude dependency on frequency deriving from the natural frequencies of the various mass/spring systems present within the vehicle. That is, tire-road contact force modulations will be readily transmitted to the sprung mass if they possess a high frequency content near a natural frequency of the sprung mass.

Tire contact force disturbance deriving from road surface irregularities tend to have rather randomly distributed frequency content. On the other hand, disturbances arising from tire irregularities, such as "out of round," "out of balance," and radial spring rate runout, will have very concentrated frequency content dependent on the rotational velocity of the tires.

It was reported that the vibrations of concern occur at a vehicle speed of approximately 40 miles per hour. Since the rolling radius of the common heavy truck tire is approximately 20 inches, the tire will be rotating at approximately 5.6 revolutions per second at a vehicle velocity of 40 miles per hour. Thus, it can be assumed that at the speed of interest, disturbances with a high 5 to 6 Hz content are present. If a sprung mass natural frequency in the same range could be identified, it would certainly appear to be the source of the problem.

This rationale is strongly supported by the experimental finding reported to Process Engineering by Littleton Research and Engineering Corporation (Report C-236, June, 1974). This report cited experimental data indicating that the most severe vibrations measured on the sprung mass of the subject vehicle occurred near a vehicle speed of 40 mph and at frequencies rarely outside a 4.5 to 6.5 Hz range.

In accordance with the preceding discussion, the subject vehicle was examined in order to derive estimates of its natural frequencies in both the pitch (i.e., rotational motion about a lateral axis) and bounce (vertical linear motion) modes.

Pitch Mode Analysis: With the aid of drawings provided by Process Engineering, calculations were made indicating the pitch moment of inertia of the sprung mass about its own center of gravity (I_{yy}) to be approximately 860,000 in-lb-sec^2. Data derived from laboratory experiments conducted previously by HSRI on tractors and trailers fitted with four spring tandem suspensions indicated that the total spring rates of the trailer and tractor rear suspensions could be estimated to be 28,000 lb/in and 20,000 lb/in, respectively. Given the geometry of the trailer, a total spring constant (K_{yy}) for rotational motion of the trailer sprung mass about its center of gravity of 1.1×10^9 in-lb/rad was calculated. From the equation

$$f_{yy} = \frac{\sqrt{\frac{K_{yy}}{I_{yy}}}}{2\pi} \qquad (1)$$

a natural pitch frequency (f_{yy}) of 5.6 Hz was calculated.

Bounce Mode Analysis: Process Engineering personnel indicated the total weight of the subject vehicle to be 21,000 lb. Assuming the unsprung weight to be 3,000 lb., the sprung weight (W) is 18,000 lb. Combining the tractor rear and trailer spring rates, a total vertical spring rate (K_z) of 48,000 lb/in results. From the equation

$$f_z = \frac{\sqrt{\frac{K_z g}{W}}}{2\pi} \qquad (2)$$

a natural bounce frequency (f_z) of 5.1 Hz was calculated.

CONCLUSIONS AND RECOMMENDATIONS

The above analysis, supported by the data presented by Littleton Research (Report C-236, June, 1974), indicated strongly that the ride problem experienced by the carbon monoxide trailer derives from the excitation of the vehicle sprung mass by tire-road contact forces arising from tire irregularities and having a high frequency content near the natural frequency of the sprung mass in both the pitch and bounce modes.

Several avenues of recourse appear to present themselves, namely:

1. Remove the tire irregularities which provide the excitation forces.

2. Alter the frequency content of the excitation forces.

3. Alter the natural frequencies of the sprung mass.

Only the third remedy is promising.

Of all the irregularities of tires which may lead to the culprit excitation, only the matter of "out of balance" is conveniently addressed by the vehicle owner. Given the state-of-the-art of heavy truck tire manufacturing, one can safely say that other significant tire irregularities will be present, regardless of correction efforts.

Frequency content of the excitation could be altered by mounting smaller diameter tires. Thus, the critical 5 Hz excitation regime would occur at lower vehicle velocities at which the vehicle presumably spends less time. Given gross tire load considerations, however, this route does not seem too promising.

The natural frequencies of the sprung mass may be altered most conveniently by adjusting suspension spring rates. Although the variations which may be accomplished by changing steel springs on the vehicle's existing suspension would be insignificant, converting to air spring suspension would likely be most helpful. The spring rates of truck air suspensions are considerably lower than those employing steel springs, such that the sprung natural frequencies might be expected to be dropped to roughly half their initial value if air suspensions were employed.

Lowering the natural frequency of the sprung mass would result in the tire force excitation frequencies being "tuned" to the sprung mass frequency at lower vehicle velocities. If the natural frequencies were cut in half, one would expect the most severe vehicle vibrations to occur at vehicle velocities of about 20 mph, rather than 40 mph. Since it might be expected that sustained operation at 20 mph would occur very infrequently, the use of air suspension could be a satisfactory solution to the ride problem. The most satisfactory performance would probably derive from employing air suspensions on both the trailer and its attendant tractor.