SINGLE PASS COLLIDER MEMO

CN- 236

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DATE: 6/16/83

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TITLE: RECOMMENDATIONS FOR ON-SITE VIBRATION STANDARDSI. Introduction

This note is to call attention to the fact that unless certain common sense precautions are observed, the luminosity of the Collider may be adversely affected by otherwise preventable ground vibrations.

Previous work¹ indicates that ground vibrations can be thought of as being caused by the sum of (a) natural and (b) cultural (i.e., man-made) effects, of which the latter can be further divided into uncontrollable and controllable.

Examples of category (a) include:

- i. pulses of short duration from local earthquakes;
- ii. longterm (~ hrs.) disturbances from distant earthquakes;
- iii. wind effects on trees and structures, waterfalls, etc.;
- iv. continuous microseismic noise originating, for example, from wave action.

Examples of category (b) include:

- i. traffic, both on site and off site;
- ii. construction activity on site and off site;
- iii. assembly of equipment in nearby I.R. Halls, even footsteps in the tunnel;
- iv. continuously operating machinery.

This note addresses question with respect to category (b) iv., only.

As a guide, the order of magnitude of amplitudes and frequencies of presently, (on site) known noise polluters is described in relation to naturally occurring disturbances and to the tolerances required for successful Collider operation. Some methods of mitigating the effects of on site machinery are suggested. Finally, a vibration tolerance level specification is recommended as well as a mechanism to police adherence to such standards.

II. Order of Magnitude of Naturally Occurring Disturbances

Figures 1a and 1b, taken from the literature^{2,3}, depict time averaged spectra of ground motion to be expected from natural sources that are in no way controllable. One notes a very rapid fall off with frequency, no doubt resulting from the increasing attenuation coefficient with frequency of sound waves in the earth.

The Brune and Oliver² curves show maximum, average and minimum amplitude values. Variations within this band may be related to the state of tranquility of the Pacific Ocean.

Measurements on the SLAC site^{1,5} taken well away from known local sources, have indeed yielded values within these expected limits. Figs. 2a, 2b, 2c.

III. Tolerable Levels of Ground Motion

Although the Beam Dynamics Task Force has not completed its detailed studies with respect to magnitude and possible correlations of magnet displacement errors preliminary indications combined with earlier calculations,⁴ show that magnet to adjacent magnet "high frequency" displacements should not exceed approximately 0.1 micrometers. At this point, one should note that if the source of vibration is far removed from the SLAC site in terms of the size of the site, (plane wave approximation) then at some low frequency one would expect the whole site to move

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coherently and, therefore, no relative displacements of high gradient magnets should occur. Assuming a sound velocity in the earth as low as 2 KM/sec, this would be true for frequencies below 1 Hz. Further, one should note that the upper side of the bandwidth of any feedback system is limited by the rate at which it receives its error signal. If this signal is derived from some beam-related monitor, sampled at the pulse rate of the accelerator (pps), then it has been pointed out ⁶that the maximum frequency of the disturbance that can be controlled is limited to $f \approx \text{pps}/6$. For 180 pps operation this is 30 Hz, but under tune-up conditions, (say at 10 pps), this frequency will be as low as ~ 1.5 Hz.

We assume for the moment that ground vibrations are transferred to gradient magnets with neither amplification or damping, although both of these factors will need to be considered in the design of their supports. From the above discussion we are led to conclude that ground vibrations in the frequency range above 1 Hz with amplitudes above 0.1 microns should be considered potentially dangerous.

IV. Characteristics of Some Identified Sources

From the very inception of ground motion studies in September 1979, every spectrum taken shows a number of discreet lines. At first thought to be instrumental, some of these lines were subsequently identified with a few major pieces of reciprocating machinery on site. Most have higher harmonic content.

To list a few:

		Vertical p/p Amplitude at 20 feet
(a)	Hydrogen Compressor, Bldg. 113, Horizontal Piston,	4.50 Hz
(b)	Bubble Chamber 40", Bldg. 111, Horizontal Piston,	10.0 pps
(c)	Rotary Helium Compressor, Bldg. 127	59.0 Hz $\sim 1 \mu$
(d)	Air Compressors, Bldg. 007, Ingersoll Rand Vertical Piston	5.25 Hz loaded $\sim 4 \mu$ 5.35 Hz unloaded
(e)	2 Air Compressors, Bldg. 023, Ingersoll Rand Vertical Piston (2 x 75 Hp)	6.00 Hz unloaded $\sim 5 \mu$

We note that item (a) is the source that is disturbing the highly directed synchrotron radiation beam lines at SSRL - most likely by vibrating mounts of the high beta quads.

V. Attenuation of Amplitudes with Distance

(a) Theoretically, the amplitude of a disturbance in a homogeneous and continuous medium should vary with distance in the form:

$$\frac{A_1}{A_0} = \frac{r_0}{r_1} e^{-\alpha(r_1 - r_0)}$$

In practice, the disturbing source may be on the surface of the ground and the machine below in layered medium of varying composition, so that a more complicated situation not unlike that found in geophysical prospecting obtains. Experiment is, therefore, in order.

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First, a comment on the value of α , the attenuation coefficient for sound in the earth. The Table in Appendix A, Reference 1, shows values around 3×10^{-8} f sec/cm for sandstone and limestone. This translates into an attenuation ratio (exclusive of the $1/r$ term) for a 6 Hz disturbance at a distance of 1000 ft to

$e^{-3 \times 10^{-8} \times 6 \times 1000 \times 30} = e^{-.005}$. In other words, negligible effect. If loose sand, gravel or clay are encountered, this will not be true.

(b) We have used the 2 compressors in Bldg. 023, 75 H.P. each which run all the time, as a source and measure their signal amplitude as a function of distance. The resulting data is shown in Fig. 3.

The scatter of points is probably indicative of ground conditions, but a $1/r$ trend is clearly there. The data also imply that since the distance of closest approach of this major source to the BSY is about 650 ft., this source is just barely tolerable. The compressors in Bldg. 007 must be attenuated by at least an order of magnitude.

This data can be used to very crudely estimate the seriousness of other devices. One might assume that source amplitudes of similar undamped low frequency reciprocating machinery scale as the square root of their horsepower rating.

VI. Mitigation of Disturbances

Some counter measures that come easily to mind include the following:

- (a) Move the source far enough away from SLC beam lines.
- (b) Isolate the source by an appropriately designed massive platform.
- (c) Replace low frequency reciprocating machinery with devices which employ well balanced rapidly rotating turbine blades.

The solutions finally adopted will depend on some mix of capital, installation, power and maintenance costs considerations which are beyond the scope of this report. It is worth noting, however, that it is generally easier to ameliorate the source rather than the receiver.

VII. Recommended On-Site Vibration Standards for Machinery

Whereas:

1. There exist certain levels of naturally occurring ground motion beyond our control.
2. These levels are generally below levels that are tolerable or can be reduced by feedback during Collider operation.

Be it Resolved That:

1. A policy be established that limits noise from steady-state controllable sources not to substantially exceed those produced by natural sources at any floor that supports a sensitive SLC component. (See Fig. 4)

VIII. Policing the Policy

The reader will have noticed that this policy does not really have rigid rules. Clearly, the less noise the better, but there are many considerations, not the least of which is cost, that play a role. The enforcement of the standard is, therefore, best left to the collective judgement of a duly appointed technical review committee.

References:

1. Some Comments on Ground Motion, AATF/80/18, G. Fischer, March 1980.
2. J.N. Brune and J. Oliver, Bull. Seismology Soc. Am. 49, 349 (1953).
3. Franti et al., B.S.S.A. 113 (1962).
4. H.Wiedemann AATF 79/7 Sept 1979
5. Some Measurements of Ground Motion at SLAC, S. Whitaker, CN-223, 4/28/83.
6. R.Stiening Collider Note CN-14 Feb 1980
7. There exists a whole industry dedicated to this enterprise, for example, see Mason Industries, 3335 Pico Blvd., Los Angeles, CA 90023.

Fig. 1. The seismic noise of the earth's surface.

from: Brune and Oliver REF 2.

FIG 12

FIG. 3. The spectra of seismic noise recorded at 16 geographical locations.

from: REF. 3

Fig 1.6

FIG 2a

Amplitude in microns PP →

FIG 2b

FIGURE 2 C

GROUND MOTION: PEAK-TO-PEAK AMPLITUDE vs. FREQUENCY (January 1983)

NOTE: Bldg. 007 contains 2 heavy air compressors.

FIG 3

FIG. 4 Proposed Vibration Limit for steady state noise of floor supporting sensitive SLC components