LIGO-T880056-00-R

VIBRATION ISOLATION USING RUBBER AND METAL SPRINGS: AN OVERVIEW OF PAST EXPERIENCES AND THE PLANNED TESTS IN THE GRAVITATIONAL PHYSICS LABORATORY AT CALTECH

WRITTEN BY: Yekta Gürsel **September 1, 1988**

I. Introduction

The 40 meter prototype Laser Interferometric Gravitational Wave Detector at Caltech relies on multiple stacks of rubber and lead for its first stage of seismic isolation. An additional stage of isolation is obtained by suspending the test masses from the top plate of the rubber-lead stacks. This arrangement works very well for the prototype. However, the same design can not be used in LIGO receivers because of the stringent requirements on the level of outgassing that is allowed in the chambers. The purpose of this memorandum is to give an overview of the past experiences in the laboratory in using rubber and metal springs as vibration isolators and to describe planned tests of the newer designs which are candidates for vibration isolators in LIGO receivers.

II. Stacks with Rubber Exposed to Vacuum

The current vibration isolation stacks in the 40 meter prototype use rubber erasers that are exposed to vacuum. These were chosen for their low spring constants and their "acceptable" outgassing rates. Tests were performed on them to determine their outgassing rate by an undergraduate student, and he found that their outgassing rate was better than other kinds of rubber which were as soft as these. The erasers were then adapted as the spring part of the vibration isolation stacks. The performance of the stacks is still about the same after being in vacuum for approximately five years. However, some unexpected things surfaced after the stacks had been exposed to vacuum for an extended period of time. A viscous fluid started to ooze out of the erasers and collected on the supports and on the central beam splitter mass in small pools. We guess that this fluid is a remnant of the solvent that was used in casting the erasers. This is certainly unacceptable for any decent vacuum system. One might ask the question why the elastic materials that are known for their "good" behavior in vacuum were not used initially. The answer is that such materials tend to have a rather large spring constant which makes them useless as vibration isolators. Recently we started experimenting with solvent free rubbers such as two-part RTVs. It is possible to make very soft rubber compounds by adjusting the ratio of the two parts that are mixed together. Since the silicone rubber compounds are resistant to degradation at relatively high temperatures, it is possible to pre-bake these in order to reduce their outgassing rate and to take out any remaining uncured rubber compound. We installed a vibration isolation stack using one of these rubber compounds as a vibration isolator for our passive mode cleaning cavity. After being exposed to vacuum for several months the rubber shows no sign of anything oozing out of it. However, the outgassing rate is still too high to meet the stringent requirements for the LIGO receivers. Much more research is needed to determine whether an exposed rubber system is suitable as a part of the vibration isolation system in the receiver design for LIGO. The properties of elastic materials which are soft enough to make a good vibration isolator have to be examined after they are exposed to vacuum for an extended period of time. Because of this, such research is likely to take a very long time and the results from it may not be available in time to be considered as a part of the first receiver design.

III. Encapsulated Rubber Springs

A solution to the problems mentioned above is to encapsulate the rubber in some "material" which prevents the vapors and the liquids escaping from the rubber compound from contaminating the high-vacuum chambers. There are several proposed methods to accomplish this feat, although none of these methods have been tested extensively and none are "proven" to work. In the following sections, I will examine some of these methods.

IV. "Vacuum" Encapsulated Rubber

This idea is first introduced by Ernie J. Franzgrote of LIGO staff. It proposes to put the rubber compounds in separate chambers which are not completely sealed from the main high-vacuum chambers. The tops and the bottoms of the chambers holding the rubber compound are attached to the masses that form the massive part of the stack while the rubber is squeezed in between to provide the spring action. The tops and the bottoms however, are detached from each other by a small gap which allows the rubber to be compressed. The idea is to pump out the small chambers that are housing the rubber compounds separately from the main chambers at a higher pumping speed. This creates a flow of gas and vapor out of the main chambers and into the chambers that are holding the rubber which prevents the vapor escaping from the rubber from entering the main chambers. Although it is quite possible to arrange the pumping lines for a multi-stage stack in such a way that they do not short-circuit the isolation provided by the rubber, this method suffers from the small dynamic range of the stack which is caused by the necessity of having a small gap in order to achieve a high pumping speed with a reasonably fast pump and reasonably sized pumping lines. Also, in the case of a pump failure, the material escaping from the rubber can potentially contaminate the main chambers. There are currently no plans to test this method, but this may change in the future.

V. Sealed Bellows Encapsulated Rubber

Another scheme to stop the rubber from contaminating high-vacuum chambers involves encapsulating the rubber in "soft" metal bellows. This is first introduced by Ron Drever. The idea is that the metal bellows can be made much softer than the rubber to minimize the possibility of the metal short-circuiting the isolation provided by the rubber. The encapsulation is done in the following manner: The rubber is placed inside the metal bellows, the bellows is coated on the inside with a compound that is designed to damp the vibration of the bellows. The bellows is then sealed and evacuated. The evacuation may be necessary to prevent the air inside the bellows from short-circuiting the isolation provided by the rubber against relatively high-frequency sound waves. This whole assembly is then used as the spring in a vibration isolation stack. There are several problems with this approach: First of all, the bellows can not be arbitrarily soft since it has to withstand a differential pressure of one atmosphere between inside and outside. The sound waves can travel through the metal of the bellows in the longitudinal mode which will not be damped by the coating inside the bellows very well. Since the bellows is sealed, the height of the stack will change as the vacuum chamber is brought back to atmospheric pressure. The softest metal bellows that can withstand the pressure difference of one atmosphere are welded bellows which are made out of stainless steel. Because of the method of construction these bellows are much more expensive than the ordinary corrugated bellows. Despite these problems, this seems to be the most promising approach at the moment. We decided to test this method by purchasing a welded, stainless steel bellows which has the appropriate dimensions to be used in the vibration isolation stacks for our 6 foot chamber. The testing procedure involves constructing the bellows encapsulated rubber spring as described above, and actively measuring its transfer function under load in vacuum. It seems at first sight that it is difficult to load a single bellows at the loading rates required without it becoming unstable. The solution to this problem is to use a loading platform that is supported by three exposed rubber springs and measure its transfer function. Then, one repeats the measurement with one of the rubber springs replaced by the bellows encapsulated rubber spring. The bellows needed for this test is on order and it is expected to arrive soon.

VI. Vented Bellows Encapsulated Rubber

One way to overcome some of the problems associated with using sealed bellows encapsulated rubber is to use a "vented" bellows scheme in which the bellows do not have to withstand a pressure differential as large as an atmosphere. This can be arranged by pumping the bellows separately and synchronously with the main chamber with the aid of an active control system. The control system monitors the pressures in the chamber and in the bellows and adjusts the pumping (or venting) rate of the bellows to hold the pressure differential below a certain value. Since the pressure differential is not large, the bellows can be made as thin as possible. This will improve the isolation provided by the bellows. This method also guarantees that the height of the stack will stay the same whether the chamber in vacuum or at atmospheric pressure. In a multi-stage system it is possible to arrange the pumping lines so that all of the bellows can be pumped (or vented) by a single line with an automatic valve outside the vacuum chamber without short-circuiting the isolation provided by the rubber inside. Since the bellows can be made out of very thin metal sheets, corrugated bellows can be used without compromising the low spring constant requirement. This will reduce the cost of the bellows significantly. Also, the bellows can be made very small without being very stiff. This may be needed for secondary isolation stacks on top of the primary ones. The problem with this method is that it is very fragile. If the active control system fails, the bellows will burst contaminating the high-vacuum chambers in the process. Since bellows are very thin, they can easily be damaged by accidental mishandling during installation or modification of the receiver test masses. We may test this kind of encapsulation in the near future.

VII. Metallized Plastic Pouch Encapsulated Rubber

Another way of sealing rubber is to follow what the vacuum packers of food and other items do. They use a special material that constitutes a good vapor barrier which can also be sealed well. This material is made out of two laminated layers of plastic: Polyethylene and mylar. The polyethylene layer gives the property of making good seals since that plastic is well known for its stickyness. The mylar layer forms the vapor barrier. The object to be sealed is placed in a bag that is made out of this material with the polyethylene layer facing inside. Then the entire assembly is put in a vacuum chamber and the air is pumped out. The bag is then heat-sealed under vacuum. If one uses this kind of a bag to encapsulate rubber, one is still putting material in the vacuum chambers that can potentially outgas and contaminate the high-vacuum chambers. One way to overcome this difficulty is to use the same material with a third layer made out of aluminum. There are two ways of putting an aluminum layer on this material. One of them is vapor depositing which gives a very thin layer of aluminum which may have a lot of pinholes. The other way is to laminate an aluminum foil over the mylar layer. The foil is substantially thicker than the vapor deposited layer. This may seem a good way of sealing rubber, but it is not free of problems by any means. First of all, the bags have to withstand atmospheric pressure with a good vacuum inside. Since the walls of the bag is relatively thin, they will crease and make sharp corners around the edges of the object that is inside the bag. This substantially weakens the walls of the bag at those points. It will almost certainly crack the metal layer along those edges. If the pressure outside the pouch is cycled between a good vacuum and the atmospheric pressure, then the pouch will expand and contract and will eventually burst. A way around this weakness is to put yet another layer of heat resistant nylon or polyester paper outside the aluminum layer. Unfortunately, this brings one back to putting exposed plastics in vacuum. We will be getting samples of this material and we may test them. It is clear that much research is needed in this area before one can find a satisfactory solution. The material described above is an industry standard and it is readily available. It may be possible to custom make such a laminate from other metals and plastics which will have very good outgassing characteristics. However, the research is likely to take a long time and it may be too costly to pursue.

VIII. Metal Springs

The metal springs are used in the 40 meter prototype as the last stage of a vibration isolation stack for the passive mode cleaner cavity. This stack performs exceptionally well: The seismic noise is attenuated to a level where it is possible to observe the thermal excitations of the normal modes of the quartz tube that forms the cavity. The reason for such a performance is that all the high frequency noise that can potentially travel through the spring gets attenuated by the rubber spring stack, the metal spring forms the last stage which gives a very low frequency isolation. We have no plans at this time to test metal spring vibration isolators.