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HYSTERESIS REPORT OF THE TAMA-SAS FILTERS

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HYSTERESIS REPORT
OF THE TAMA-SAS FILTERS.

Evidence of Hysteresis in the TAMA-SAS Filters.

While tuning the MGAS blades, in particular the blades located in Filter 0, it was repeatedly observed, on top of the well expected Bi-stable equilibrium condition in the measurements when $K< 0$, that there was some very small scale bi-stability. The peculiar aspect of this observation is that, in all cases, the difference between the two equilibrium points was very small, about 1mm. Furthermore, all measurements fell along the customary position versus frequency curve without deviations. Despite this fact, two separate and repeatable equilibrium positions can be obtained if the working point is approached slowly from far above or far below, without allowing large oscillations. This small-scale anomaly was rapidly identified as Hysteresis.

When measuring the MGAS blades utilized at SAS, one can certify that the blades are in Bi-stable equilibrium condition ($K<0$) when a "gap" is observed between two equilibrium points pertaining to the same payload. Sometimes, bi-stable conditions might not be quite obvious at first. However, the distance between the equilibrium points increase until a large gap is observed, this indicates that the blades were in bi-stable condition all along, due to the particular compression. And, upon plotting the measurements taken for various payloads, the measured points of a position versus frequency graph form two separate convex curves leading to the gap, at which point both curves begin to open outwards in a hyperbolic form. In the case of normal stability, when the blades are said to be in Mono-stable equilibrium condition, this same curve forms a single concave curve, which is parabolic in nature with its minimum point representing the minimum resonant frequency of the MGAS blade.

In this experiment, what we initially thought was bi-stable condition was observed in many measurements, all falling on the same concave curve (parabola), a characteristic of a Filter mono-stable operation. Upon more careful considerations of the mechanical structure of the attachments on the Filter, it was realized that the problem could be traced to Hysteresis. The main suspects were the blades and the clamp-wedge-filter attachment system. The hysteresis is totally obvious if the data is plotted as a function of payload versus frequency or payload versus equilibrium position, graphs that are rarely used in tuning MGAS Filters for low frequencies.

In principle, any mechanical system will have some type of hysteresis, this should also happen in the MGAS blades themselves. Note that the system could, in principle, be at the same time in bi-stable condition and have hysteresis along the two hyperbolic arms. In fact, upon analyzing the measurements, we found evidence of both types of phenomena.

Following the hysteresis measurements, we performed hardness measurements on all the components of the attachments. We first suspected soft blades due perhaps to a bad precipitation hardening process. A hardness test (Rockwell) showed that the blades had the expected hardness of 51 to 54, a hardness level which in previous measurements of the blade's maraging steel proved it to be virtually free from hysteresis. Instead, it was found that the wedge and clamp had a hardness of about 4 to 5 Rockwell. It became obvious that this extreme mismatch was the most possible cause of the observed hysteresis.

<u>The MGAS tuning experiment.</u>

Figure 1: Pictures of the experimental set-up.

<u>A note on the experimental procedure.</u>

The three main parameters of interest are radial compression, load, vertical equilibrium position, and vertical resonant frequency. With these quantities, the optimal condition of the system can be achieved by a process called *tuning,* both of the radial compression, the load, and the vertical equilibrium position (the working point of the filter). The compression parameter, like load, is determined and adjusted directly; the position and frequency parameters are consequences, which are measured indirectly. For each compression level, vertical equilibrium position and vertical resonant frequency are recorded for many different load levels. The radial compression is adjusted until the required vertical resonant frequency of the MGAS is obtained at the filter working point (the minimum in the vertical position versus vertical resonant frequency curve). There are, of course, other "hidden variables" that affect the frequency measured and also the position; one example is damping by friction. Note that the most crucial part of this experiment is tuning the radial compression, since the vertical resonant frequency and the vertical equilibrium position can both be tuned by adding or subtracting suitable amounts of load. The radial compression has to be in the right level, so as to produce the optimal condition of the attenuation filter without any bi-stable conditions.

The standard load consists of:

1.) The wooden cage, including the iron threaded rods, bolts, washers, etc.
3.) The iron disks
4.) A device, made of aluminum, used to measure the position.

The total weight of the standard load for Filter 0 is 95 Kg.

Experimental Data:

First Set of measurements.

TALBE 1

Load[Kg]	Position[mm]	frequency[mHz]
98.020	100.00	711.20
98.148	99.000	660.50
98.148	98.900	654.00
98.277	97.500	605.00
98.277	97.100	592.10
98.406	96.000	545.60
98.406	95.500	519.50
98.534	93.900	457.90
98.534	92.500	419.10
98.662	90.400	341.40
98.662	86.500	300.90
98.790	82.900	322.60
98.790	80.600	365.00
98.919	78.400	461.50
98.919	76.400	491.20

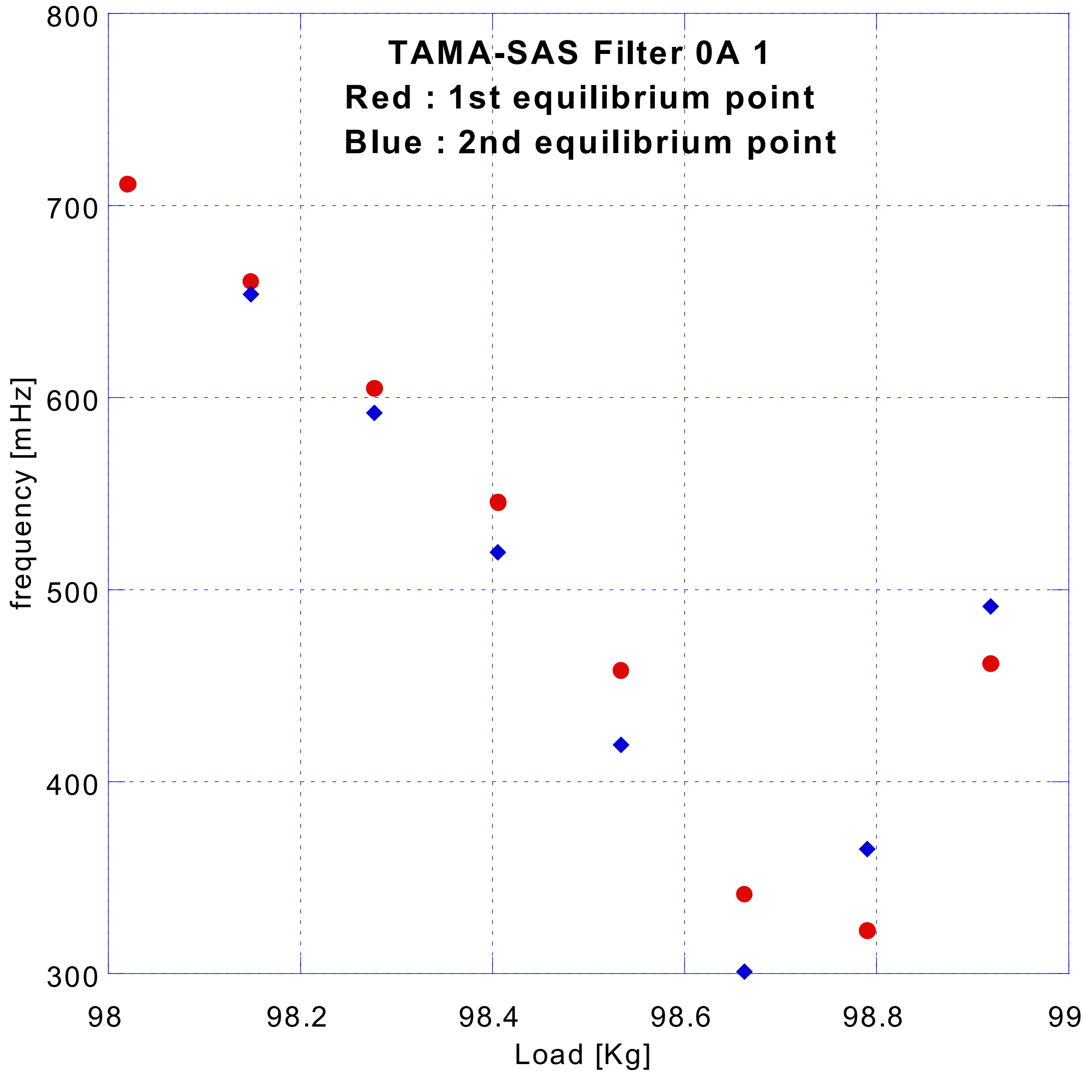

Figure 2: Load vs. Vertical Resonant Frequency.

This graph shows how for each load, there is two different frequency points.

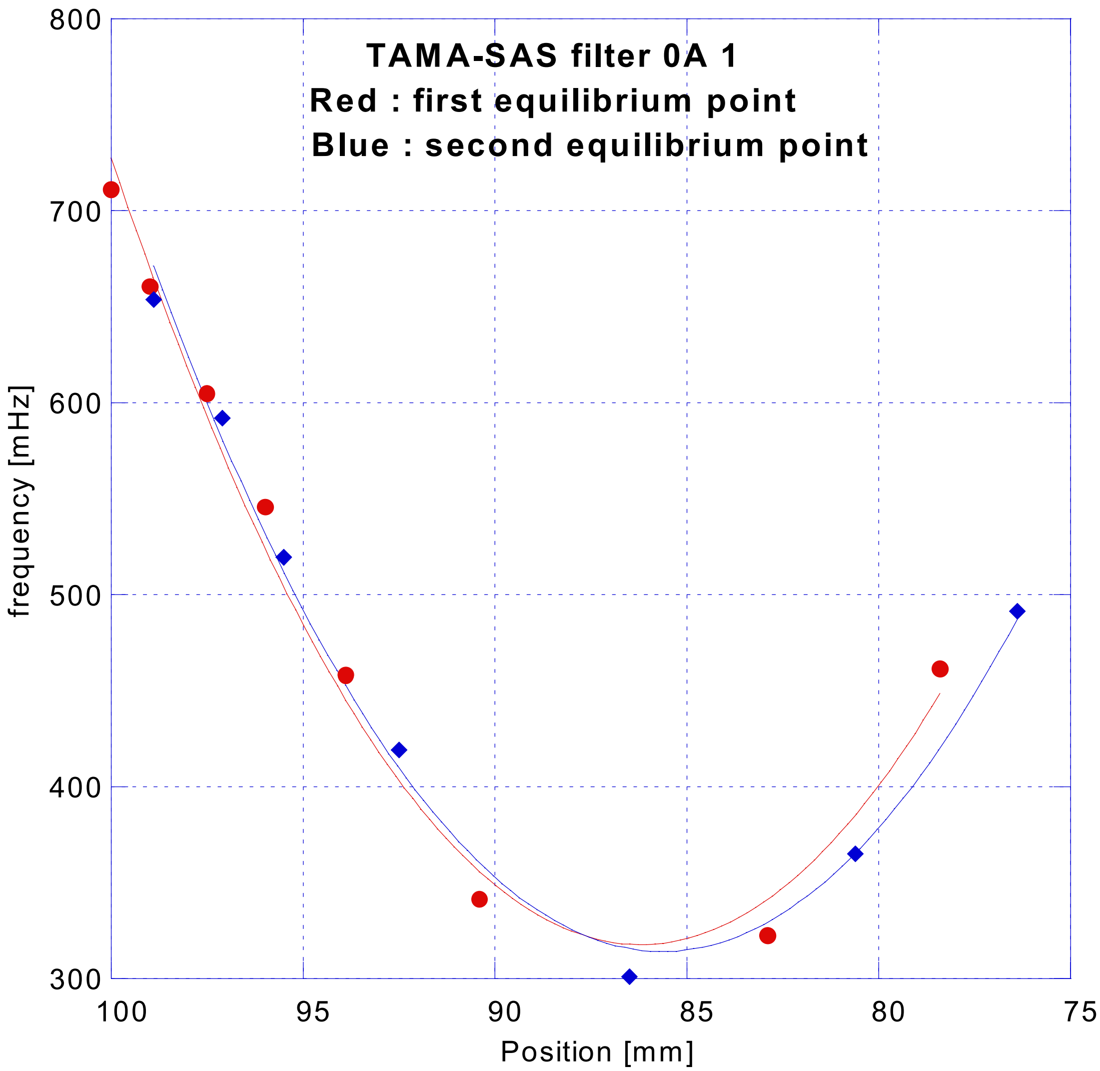

Figure 3: Vertical Position vs. Vertical Resonant frequency.

Notice how the distance in position in each measurement, the two points corresponding to the same load, increases as the system attains it's minimum resonant frequency.

Then, about 2 hours later, the same measurements were repeated for the same MGAS blade with the same initial conditions. As one can see, different data was obtained:

Second Set of measurements.

TABLE 2

Load[Kg]	Position[mm]	frequency[mHz]
98.020	99.500	699.80
98.020	99.250	679.30
98.148	98.500	641.40
98.148	98.000	620.00
98.277	96.900	581.10
98.277	96.250	556.50
98.406	95.250	518.90
98.406	94.250	478.50
98.534	92.800	422.80
98.534	90.800	369.50
98.662	88.500	311.40
98.662	83.500	309.90
98.790	80.600	360.60
98.790	79.000	414.20
98.919	77.500	468.80
98.919	76.600	492.90

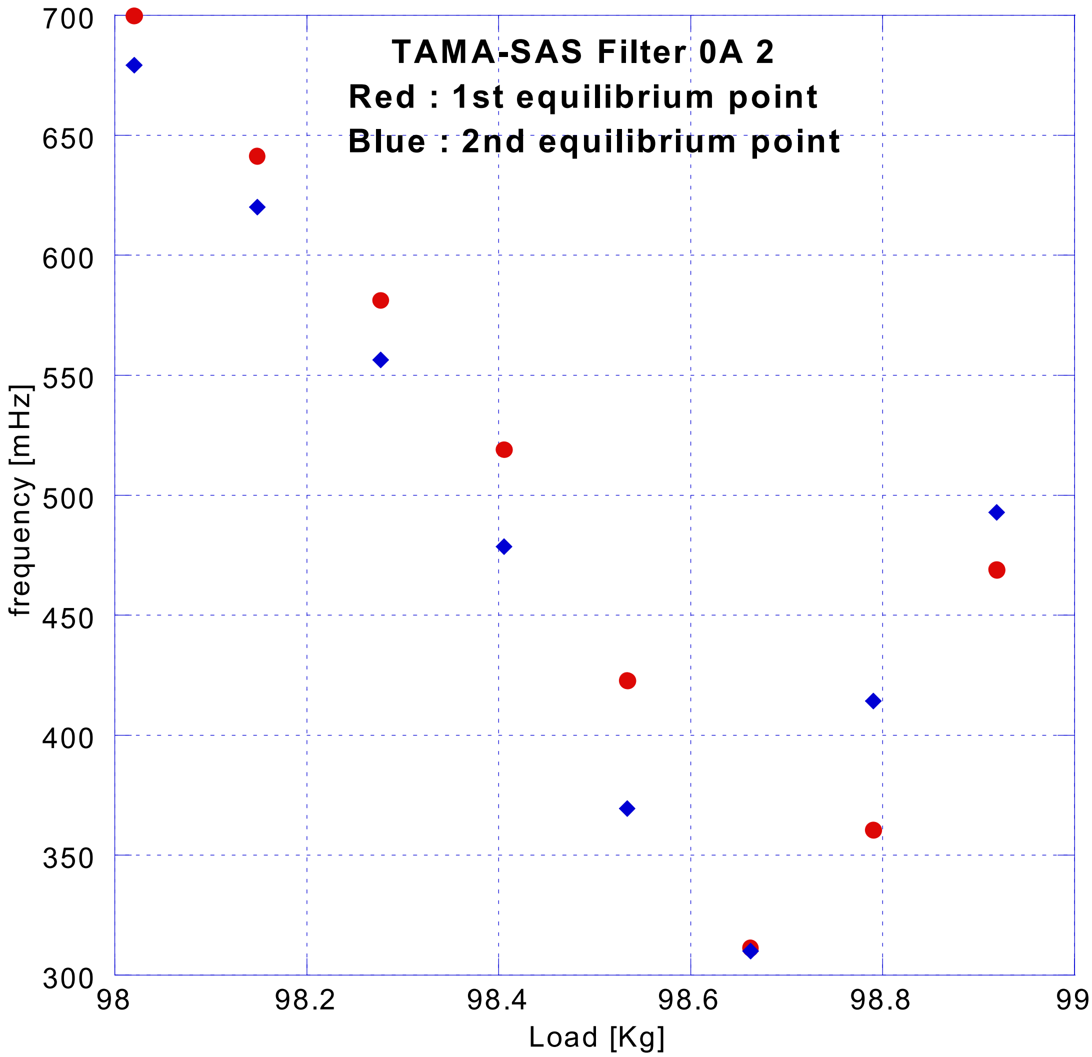

Figure 4: Second measurement of Load vs. Vertical Resonant Frequency.

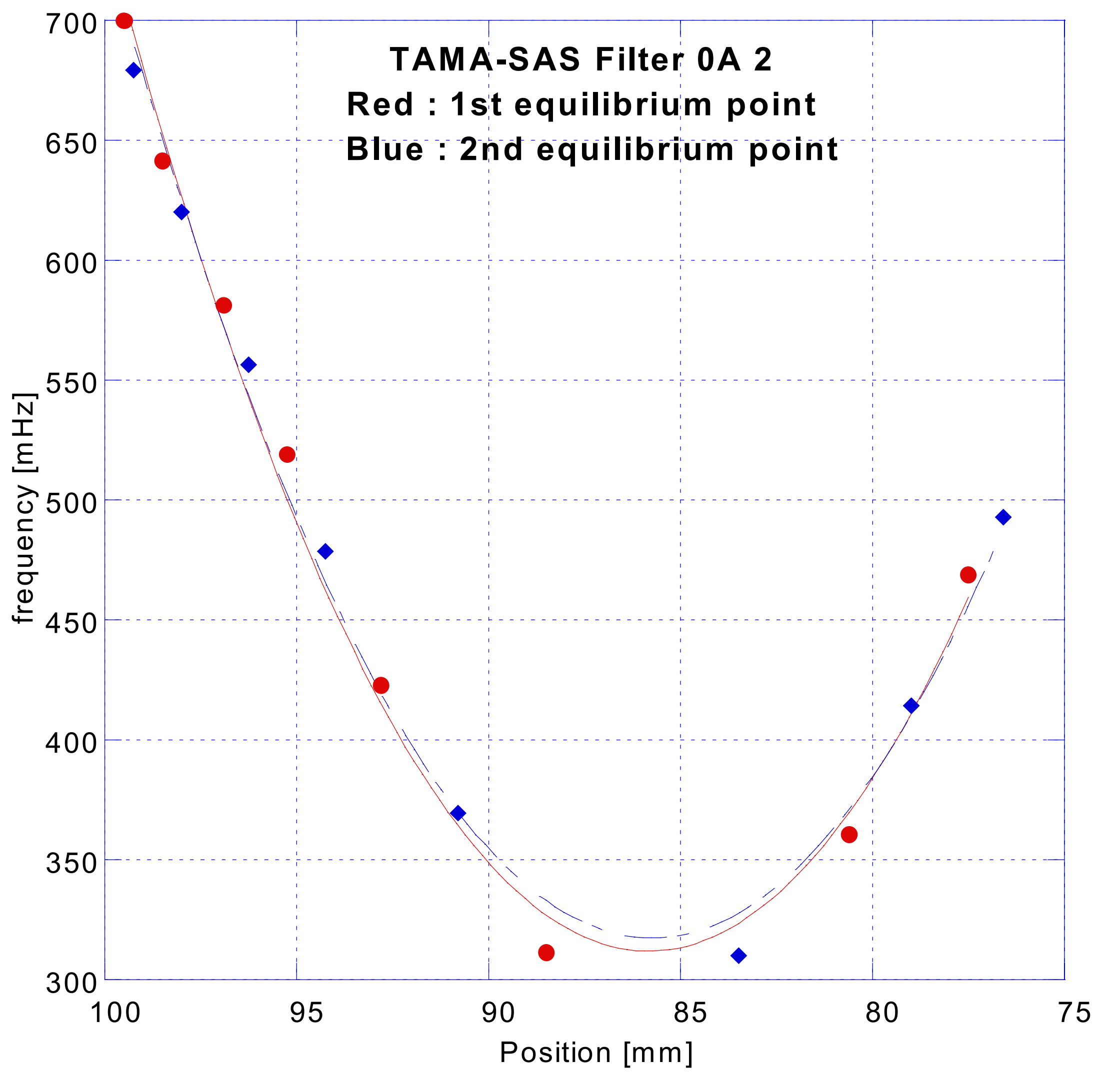

Figure 5: Second measurement of Vertical Position vs. Vertical Resonant frequency.

The following are graphs corresponding to the two sets of measurements, a total of 4 individual points per each independent parameter.

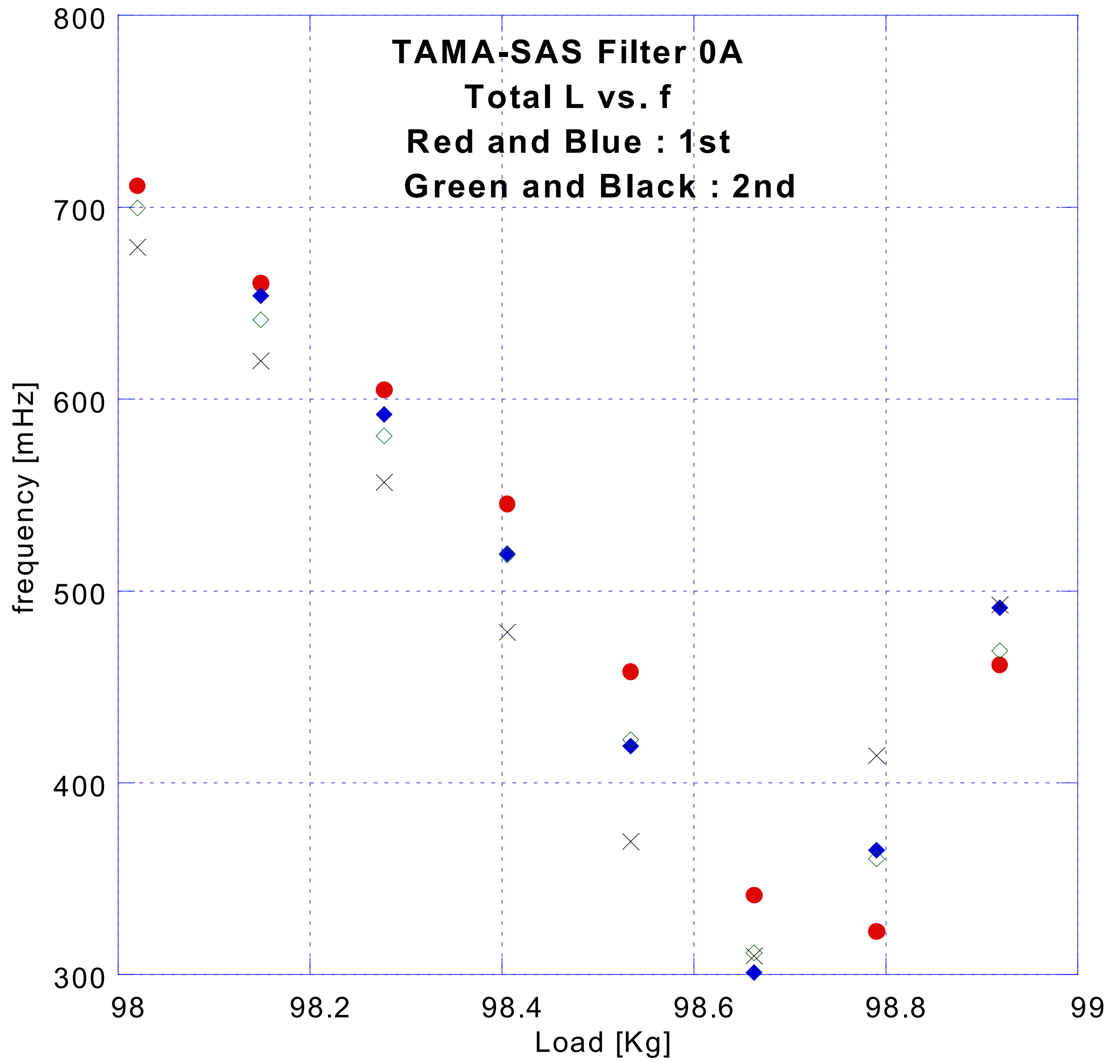

Figure 6: A comparison of the data of Figure 2 and Figure 4.

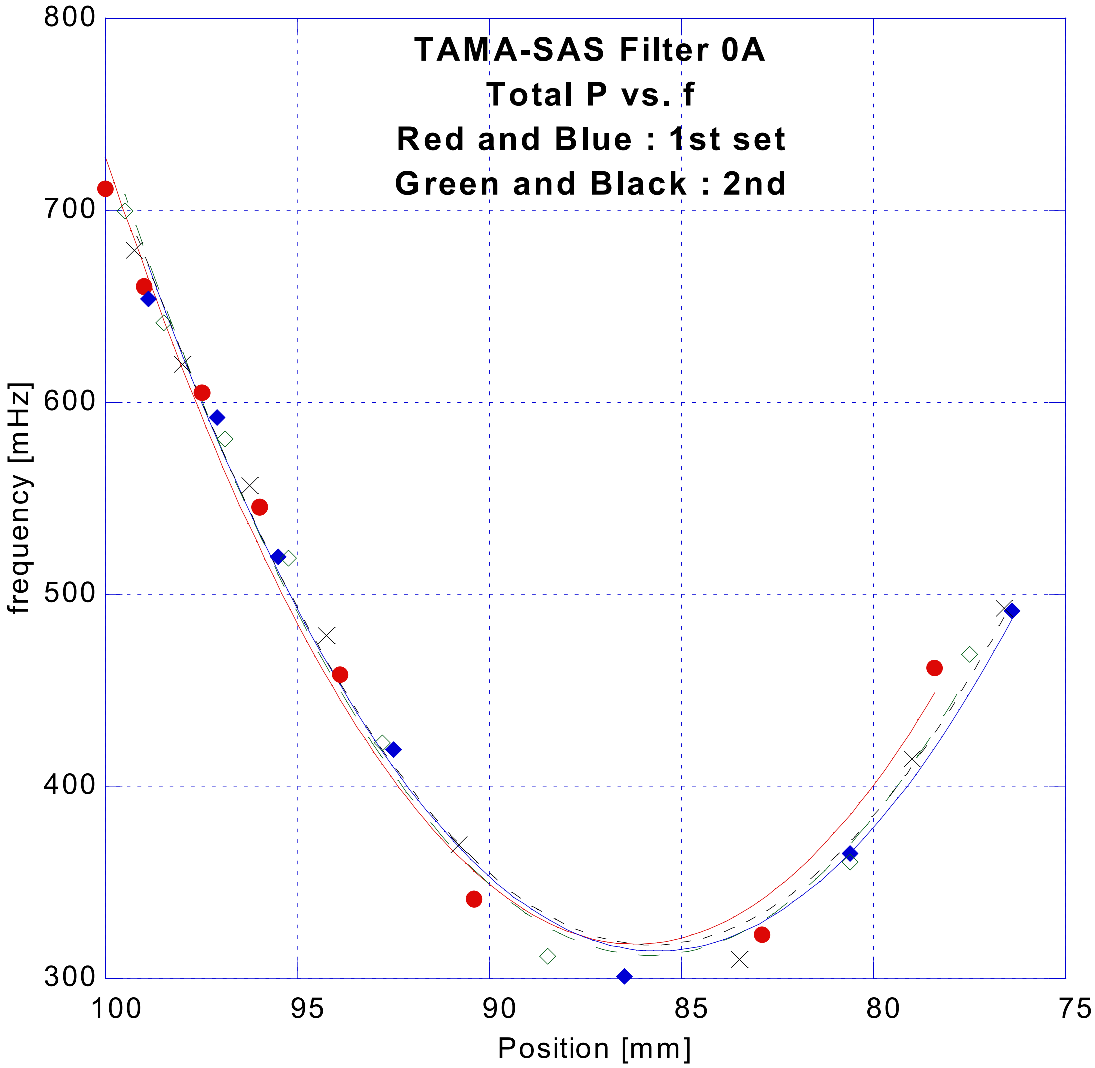

Figure 7: A comparison of the data in Figure 3 and Figure 5.

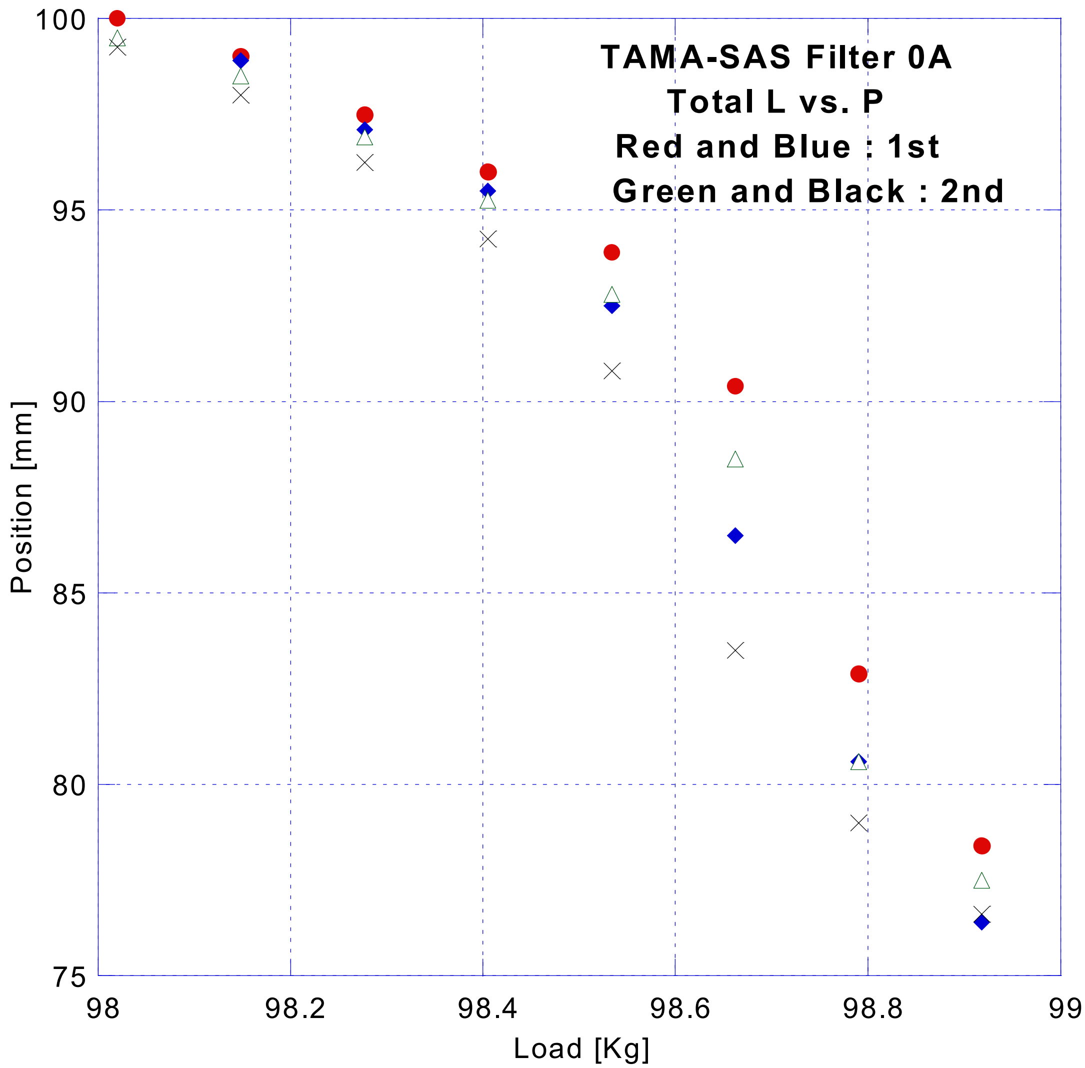

Figure 8: A comparison of the data obtained from the two tables, for Load vs. Vertical Position.

As can be seen, in the second set of measurements, a lower minimum vertical resonant frequency was obtained. It is possible that the measurements differ because the blades, and therefore the attachments, were subject to longer periods of stress and thereby altering the mechanical configuration, causing a different level of hysteresis.

Previous evidence of Hysteresis in SAS and TAMA/SAS Filters.

In previous towers, for example the first prototype "LIGO SAS Tower", hysteresis was never observed directly. One reason why the hysteresis was not observed before is that, due to the nature of this particular cause of hysteresis, it is mostly observed at low frequencies and with very small amplitude of oscillation. That is to say, the mechanical configuration of the attachments and, the strength of the materials which compose it, do not allow for measurable hysteresis. In fact, one needs to know how to identify this type of hysteresis on a system like the SAS towers, specially on the data plots, since it could be passed without noticed.

We went back to the old LIGO-SAS tower and found no visible mechanical hysteresis. The remaining wedges of this tower were measured for hardness and were found to have a Rockwell hardness above 20.

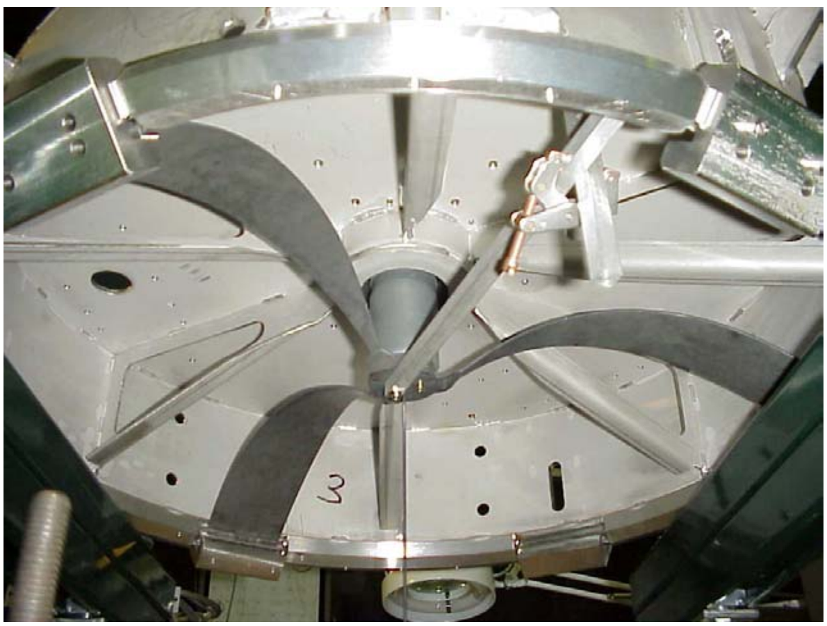

Figure 9: An underneath photograph of Filter Zero that shows the MGAS blades with the attachments used, in the TAMA-SAS attenuation towers.

Conclusion

We have now concluded that the problem lies principally with the wedge's hardness in the TAMA-SAS towers. Harder wedges and clamps are under construction to cross check this solution on a spare MGAS Filter. Further analysis will be done in this system to minimize the possibility of hysteresis, and it is hoped that this observation will shed light on future similar suspension systems.