LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO- T080095-00-R *LIGO* April 15 2008

Stress-corrosion in Maraging blades

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Distribution of this document:
LIGO Science Collaboration

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We lost track of the HAM SAS filter and tooling crates, that a year ago were prepared for shipping and sent to storage in the Sunny Slope warehouse.

The crates were finally found in the parking lot, exposed to the weather and rain.

Transportation reported that were instructed by PMA to store them outside because they did not have space inside.

Note that it is the second time that PMA's administration parks our equipment outside, against and without our technical advice. Already a year and a half ago a larger SAS tower was sent to the Sunny Slopes parking lot without our knowledge, thus potentially endangering the transportation personnel and damaging the equipment itself.

The crates found in the parking lot were all molded, unsuitable for shipment as illustrated in the figure 1.

Figure 1, photo of three of the four damaged crates next to two clean, new replacements.

We opened the two crates that needed to be shipped. The equipment inside was wrecked by corrosion, see figure 2.

We started transferring the damaged filters to clean new crates. We did this transfer by hand (PMA did not make available a space with a crane) without realizing the possible damage generated by stress corrosion of the blades.

We then proceeded opening the second crate to be shipped. This contains a smaller filter with thinner blades.

To our surprise we found that the corrosion had gone through the blades' thickness and the blades had exploded in several shrapnel-like parts inside the crate, as illustrated in figure 3 and 4.

The close-ups of figure 4 show clear signs of "classical" stress driven corrosion, where oxidation wedges penetrated, knife-cut fashion, perpendicular to the tensional stress direction, and causing catastrophic failure.

Luckily the crate and filter body contained the effects of the explosion and no damage to people ensued.

Handling of the larger HAM SAS filter, with unshielded blades, exposed us to potentially deadly danger.

We immediately closed the new crate to confine a potential explosion of this potentially much more dangerous filter.

A third crate, containing a third filter, also of HAM SAS design, but with intermediate size, was not open, while looking for a suitable location where the filters can be safely lifted and disassembled.

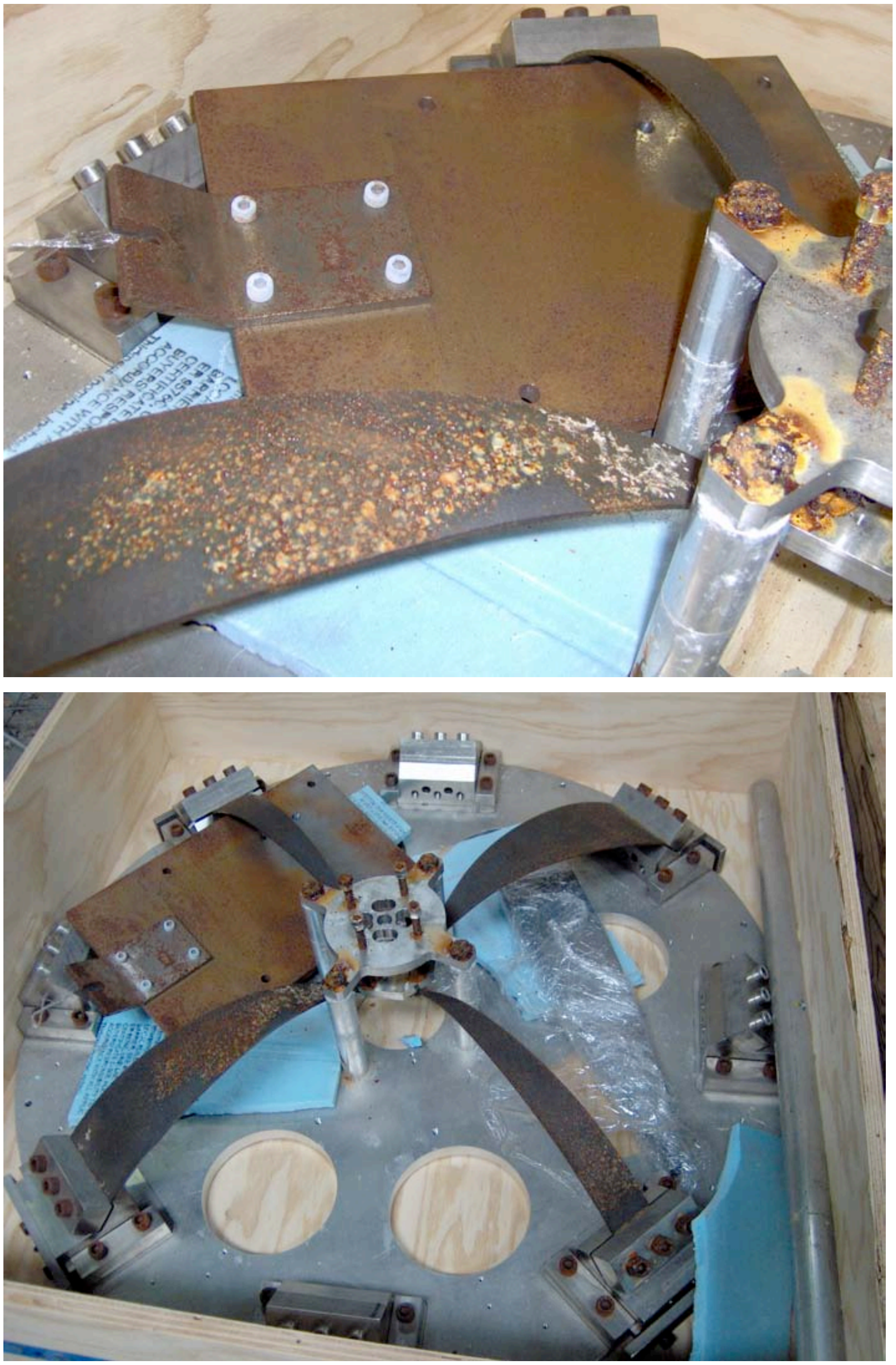

Figure 2, part of the damaged equipment (photo taken after transferring to the new crate).

All non aluminum or non stainless parts are damaged beyond repair. Even the stainless and Aluminum parts require extensive cleaning and etching.

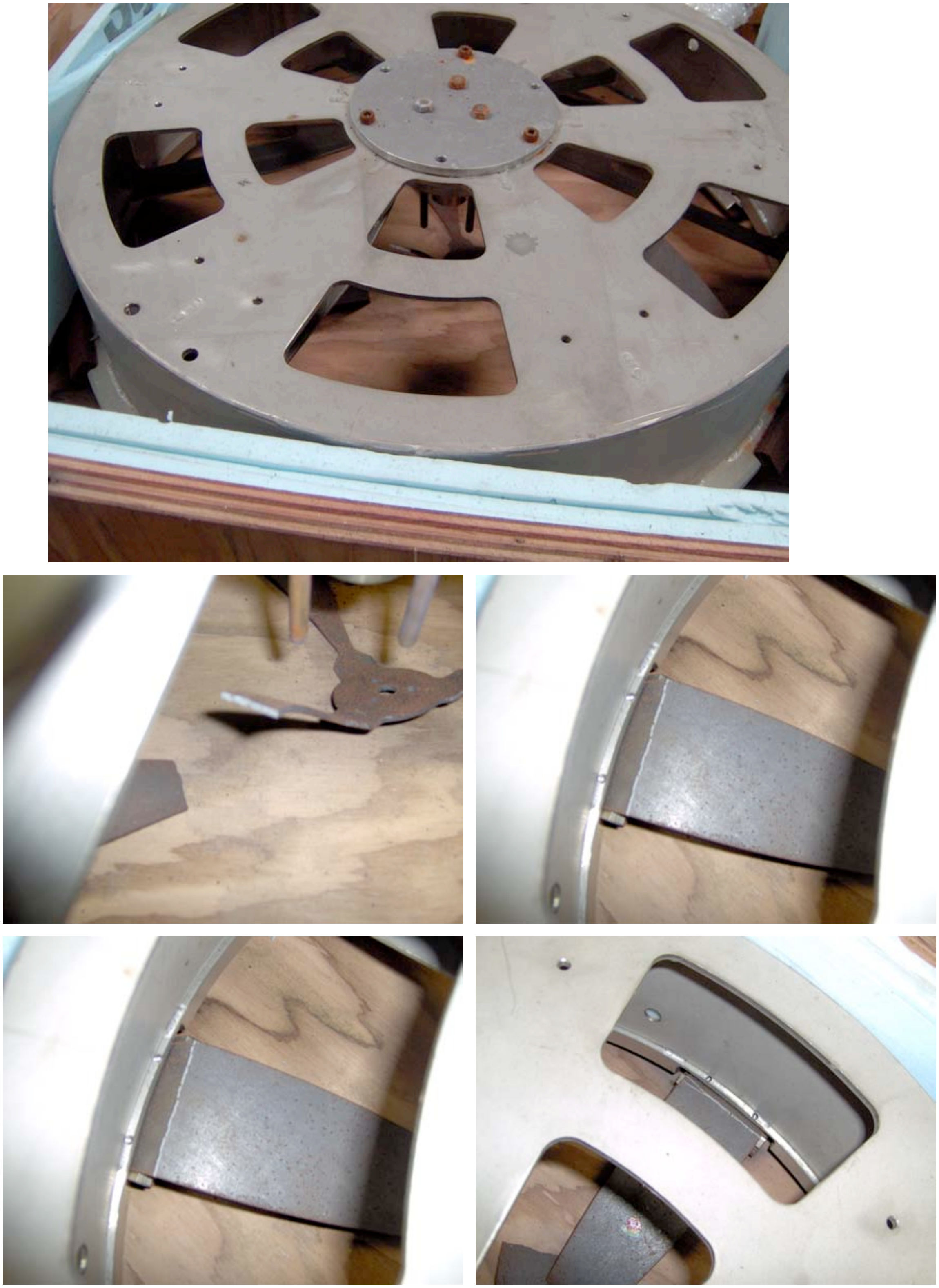

Figure 3, filter (TAMA model) with parts of blades laying at the bottom of the crate and close-ups of the broken blades.

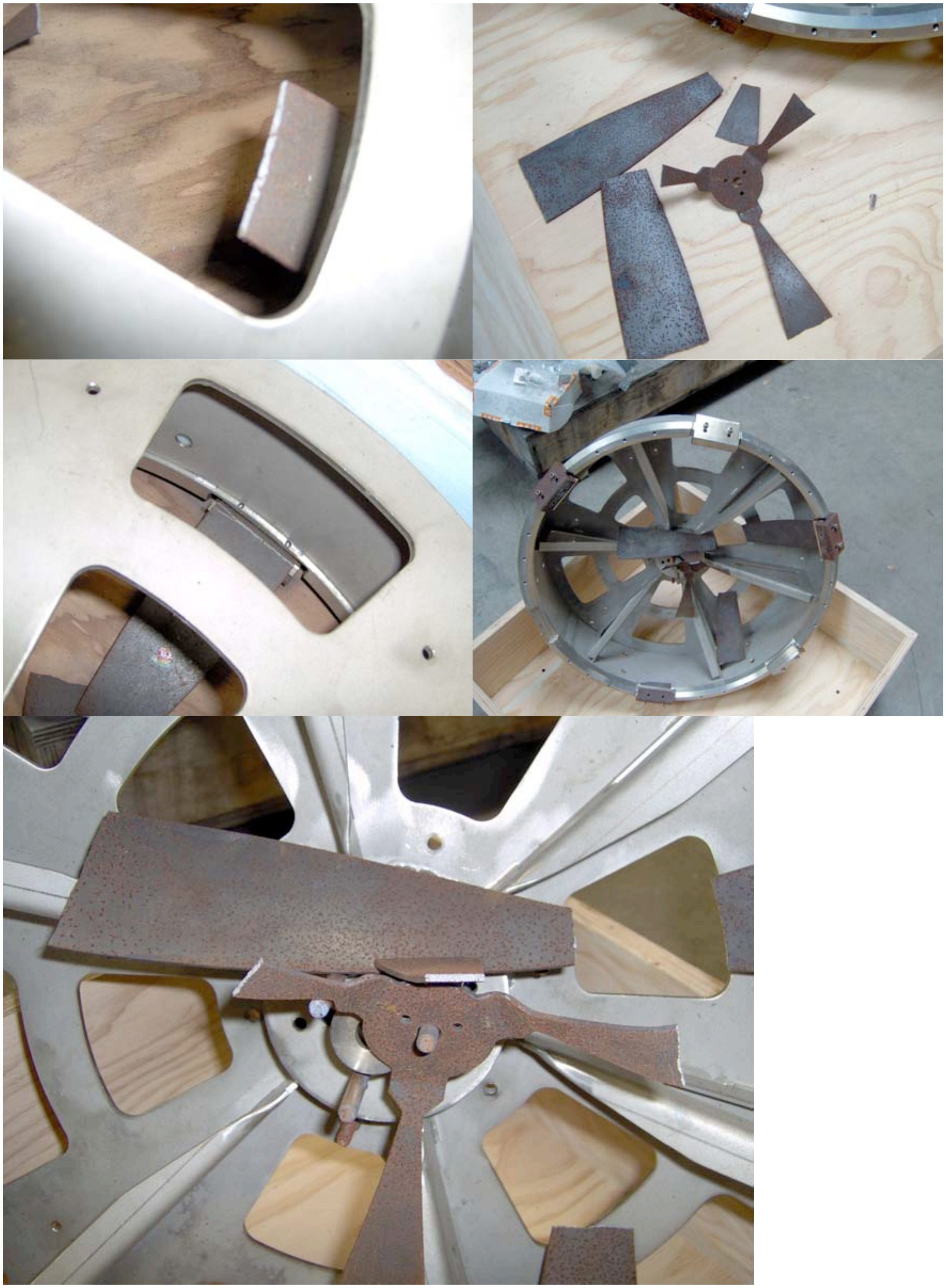

Figure 4, detail of the exploded blades, showing the effects of "classical" stress-corrosion.

Discussion.

Stress corrosion only happens on the side subject to tensional stress. Humidity enters into any pre-exysting micro-cracks opened up by the tensional stress. Iron oxyde, having larger volume than the original metal, press on the wedge, thus further opening the cracks and opening the way for more humidity and corrosion, and further expansion of the wedge. The result is thin wedges of Iron oxyde extending inwards perpendicularly from the surface subject to tensional stress.

From the blade use point of view, an important observation is that all debris show obvious curvature, despite the fact that the blades were loaded below 50% of the elastic limit.

This means that, besides the few cracks that cut through the thickness and generated the catastrophic collapse, many microscopic corrosion wedges distributed over the tensionally stressed surface must exist, and generate the observed permanent blade warping.

While a lot of corrosion was necessary to break the blades (and generate sizeable risk), even small amounts of humidity (including people transpiration) can generate small amount of corrosion wedges and micro warping of the blades. This would change the useful working load of the blade. Additionally, a myriad of small of corrosion filled wedges may lead to worsening of the mechanical noise characteristics of the blades.

To avoid this, and to guarantee an even higher level of passive safety, a thin Nickel plating (~1000 - 2000 Angstrom) is recommended.

Also it is recommended that systems containing blades under stress are stored in sealed bags with silica gel air dryer.