A HISTORY AND ANALYSIS OF HYDROGEN MASER RELIABILITY

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ABSTRACT

Hydrogen masers are an integral part of the Deep Space Network. Their use provides extremely accurate navigation about the outer planets, as well as precise location of tracking stations. To provide accurate measurements over extended periods of time, reliability of equipment plays an important role. The Deep Space Network has a number of hydrogen masers deployed and in the test cycle, which enables an analysis of reliability of several generations and breeds of construction.

A history and analysis of hydrogen maser reliability are given over a three-year period on several types of masers.

INTRODUCTION

The Deep Space Network (DSN), operated by Jet Propulsion Laboratory, California Institute of Technology for NASA, requires extremely accurate oscillators and timing systems. Navigation of spacecraft to the outer planets and Very Long Baseline Interferometry (VLBI) require long term accuracies and reliability to obtain precise spacecraft location. To that end, the DSN utilizes hydrogen masers as the precision oscillator. This paper reports the results of several years experience with hydrogen maser reliability in a field environment, and suggests modification and changes that could result in even more reliable oscillator operation.

The DSN consists of complexes located around the globe at approximately 120 degree intervals. The complexes are specifically located near Canberra, Australia, Madrid, Spain and Goldstone, California (about 120 miles from Los Angeles in the Mojave Desert). The complexes consist of one 64 meter parabolic antenna and one each 26 meter and 34 meter parabolic antenna.

*This paper presents results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS 7-100, sponsored by the National Aeronautics and Space Administration.

The 64 meter antenna is considered the prime location for each complex, and the location of the hydrogen maser for that complex. There is at least one hydrogen maser at each complex and at times two, depending upon mission criticallity and condition of the hydrogen masers.

Background

This study compiles data taken from several different types of hydrogen masers, that is, manufacturers and models. Specific names of manufacturers are omitted, as they serve no purpose for this study. As the analysis was taking place, it became evident that all hydrogen masers shared similar if not identical characteristics, therefore, catagorizing by the manufacturer is not necessary.

The study considered the following, which will be discussed in further detail below: (1) the population of hydrogen masers in the DSN, (2) length of service of instruments, (3) categories of failures, (4) number of failures in each category, (5) MTBF of each category and total MTBF of all instruments in all categories, and (6) conclusion and recommendations.

Population of Hydrogen Masers

The population of hydrogen masers used in the study was a total of fourteen. The locations of the masers varied from the field environment at the complexes to laboratory environment at JPL in Pasadena, California.

The data taken on each of the masers was from log books, files and requisitions for repair service and parts. Each maser is assigned a log book when it arrives at JPL, and a file is also maintained as a back-up source of data and as a chronological summary of events for a particular instrument.

Data presented in this study is that which was taken while the instruments were under JPL cognizance, and that which caused or resulted in failure of the units.

Length of Service of Instruments

A total of 533 months of instrument data is utilized in this study. For the 14 units, an average of 38 months, or more than three years per instrument, is the resultant data base. The longest instrument history in this study is 72 months and the shortest is seven months. Two instruments were under study for 54 months.

The 533 months of instrument history represents over 44 years of hydrogen maser data, which is believed to be the largest and longest data base on maser reliability in the industry.

Categories of Failures

Two major categories of failures became evident as data was gathered and segregated. A major contribution to failure was the VACION pumps that are used to pump the hydrogen gas from the system. All other failures were classified as OTHER, and include Autotuners, Power Supplies, Heaters and external Magnetic Fields.

The VACION pump failures consisted of two modes and totaled 21. The first type, arcing, is caused by "whiskers" growing on the titanium elements, which in turn cause temporary high voltage arcs. This indication is prevelant in older pumps and contaminated elements; that is, elements that may contain impurities in the titanium.

The second type of VACION pump failure is that which is a total short of the elements. This usually happens, again, in the older elements.

In all cases above, the eventual or immediate action was to replace the VACION pump elements. To replace the elements, the maser must be taken off line and major disassembly of the instrument is required to get to the pump elements. The maser must then be turned back on, allowed to stabilize, calibrated and put back on line. The Mean Time To Repair (MTTR) for this type of failure is 1.8 months. It must be noted, however, that the MTTR has lessoned in the past two years and is now taking slightly less than 1.5 months. The reason for the MTTR being less is because more is known about the systems and procedure utilization.

The Mean Time Between Failures (MTBF) of the 21 hydrogen masers VACION pumps is slightly more than 25 months. Therefore, one would expect to have a replacement approximately every two years, taking about six weeks to repair and regain on line performance. This result is considered to be less than adequate, in particular the MTBF. A possible solution to the problem is addressed in more detail later in concluding remarks.

In the category of "Other Failures," a total of 12 were accounted for. Those failures are of the electronic type, such as Power Supply failures, Autotuner not reacting, changes in Magnetic Field Compensation and Heater failing. On only two occasions was the hydrogen dissociator found to be low or contaminated.

The reliability factor of the electronics parts of the masers is very satisfactory. With a MTBF of 44.5 months, the apparent useful time of a maser in service for four years is about 3.7 years, including the MTTR of 1.5 months.

The indications are that with an MTBF of 44.5 months and a MTTR of 1.5 months for the electronic components, the physics portion of the Hydrogen Maser is more susceptible to failure, and possibly could prosper from indepth research.

Reliability of Total Instrument Population

By combining the MTBF numbers for the VACION pump and all other failures, a total of 33 failures ensues. With the 533 month history of the 14 Hydrogen Masers, a totl MTBF of slightly more than 16 months evolves, with the accompanying MTTR of 1.7 months. It is easily recognized that the 21 failures of the pumps seriously impaired the usefulness of the instruments. Assuming the electronics and pump were equally reliable, one could expect to use a maser for nearly two years without failure, with a repair time of just over 1.5 months. This in itself improves the over all reliability by 6 months.

Conclusion

The data base implies that the Hydrogen Maser is vulnerable from a reliability stand point, from VACION pump failure, causing a very low MTBF. When the pumps were first utilized, a 4 year MTBF was advertised by the manufacturer. The first elements were in fact more reliable than the current product, which implies a very fast degradation in the element usefulness in the past 3 to 4 years. We must explore a more reliable pumping process or possibly consider lower source pressure or better quality products from the element manufacturer

It is entirely possible that the titanium plates are manufactured with a contaminant. A close Quality Control by the manufacturer could eliminate early pump failure. Also, the manufacturer could impose very stringent requirements on the supplier of titanium used during element manufacture.

Another possibility would be to refit the instruments with chemical filter pumps, which are passive. A test instrument should be utilized and tested for all known possible failure conditions with chemical pumps. It is proported that if chemical pumps were used, two could be placed in the instrument and switched in and out as required without disrupting maser performance. The advent of this configuration could strongly enhance the current reliability figures presented in this paper.

Maser manufacturers must seriously consider improving the overall performance of Hydrogen Masers. The initial costs as well as maintenance costs and reliability, are not conducive to high performance systems in todays market. A MTBF of 36 months would entice possible users of masers, and reduce maintenance costs as well as time lost due to failures.

The history and analysis of the data presented indicates that a concerted effort be made by manufacturers to improve the reliability of the Hydrogen Maser VACION pump process. All other operations of instruments appear to be adequately reliable to serve its users in a reliable manner.

QUESTIONS AND ANSWERS

DR. VESSOT:

I think your observations are quite valid insofar as those pump elements are concerned. There is something squirrelly going on, either the metallurgy is suffering, or we are doing something we don't know about when we replace pump elements.

It is not likely that we are doing worse than we were before, we are being cleaner and more careful. So, I think it points to the fact that the titanium, as we receive it in the form of pump plates is different now than it was before.

MR. CURTRIGHT:

You mean the titanium as it is placed on the elements or the titanium prior to the placement on the elements?

DR. VESSOT:

Well, generally speaking, the material would be available in sheet form, it is chopped into plates. First, we don't know what alloy is being currently used or what grade of titanium -- there is a great demand for titanium and it seems to be rather difficult material to get.

So, what is happening now, I suspect, is that they are using whatever they can.

Secondly, the chief supplier of the pump elements moved his plant and I suspect his processing may have changed.

MR. CURTRIGHT:

I wonder if it might be advisable to look into some quality control, or quality assurance to the activities they have. I wonder if that would help?

DR. VESSOT:

That might.

Dick Sydnor has initiated as assaying of the material to see what inpurities there might be in the metal itself, which I think is a very valid route to take.

As for the hydrogen, I honestly believe that the hydrogen that we have now is as good as it was before. We pass it through palladium diaphrams which are traditionally one of the best means of purifying hydrogen. So that much I think is out.

As far as sorption methods are concerned, I believe that is the way of the future. In the distant past, and we launched a clock that would run for -- Michele Tetu was in on the test, it must have been back in 1976, but clocks had run for a year effectively on a single sorption cartridge made by the SAES company in Italy.

This technology is, I think, becoming better and we will be hearing more of this tomorrow and later in the work that has been done here at the Naval Research Lab.

This technique is that of a sponge-like material that just selectively absorbs hydrogen and you have to cope with the non-hydrogen species with a different pump. And fortunately, for us, we are working on just such a pump to retrofit the clocks that we have now in the field.

MR. CURTRIGHT:

I understand.

One of the problems I see is that when we first went into the vacion world we were led to believe that they were off the shelf items and there was no problem in getting the material, and all sorts of swell things. And I don't want to get into the same situation with the sorption pumps, where we are led to believe that this is an off the shelf item and there is no problem in replacing them, and all of a sudden we see them end up in the canoe that we are in today, with the vacion pumps.

DR. VESSOT:

Well a lot can be avoided if you are willing to inventory a fair amount of spare parts. You can't expect these companies to do so because the volume, as you have shown us, is not a very large volume. Nobody is going to get rich supplying titanium to ion pump makers.

So, I suspect that in this rather competitive economy right now, your best bet is to hedge the market and go into the metals -- this is a strategic metal, I think it is probably not a bad investment -- get it in the form of pure plates an eighth of an inch thick and see what happens. It could be better than some other investments that have been suggested.

MR. CURTRIGHT:

Definitely. Thank you.

MR. PETERS:

I think there is an obvious solution to the finite lifetime of pump elements in hydrogen masers. And this is because of developments in state selection and redesign of the overall system. It is quite clear that we can operate with the factor of at least 10 lower beam flux and therefore -- and also a pump that operates at a lower flux has much longer lifetime, does not have the sputtering problem that a pump that operates at a high flux.

We can and I am giving a paper on it later, so I won't carry on at this time -- state select much more efficiently, use less hydrogen and get more power out of a maser if we modify the beam trojectory and the overall design slightly.

MR. TOM ENGLISH:

I just wondered if you had some, at least rough idea, of what the hydrogen load on your pumps was in moles per year, or some other appropriate units? And, also, specifically, what pumps did you use on your devices?

MR. CURTRIGHT:

The pump elements are Perk and Elmer, eight-element pumps and it is a 200 liter per second pump we are using. How many moles we use per year? I don't have that information with me.

DR. REINHARDT:

Just a comment on the pump problem. We have seen similar results with the varian triode pumps, so I don't think it is manufacure unique. That points to the fact that it is the titanium that everybody is getting.