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.

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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.