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# Perpetuum PMG17 Reliability Case Report Summary

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This document presents a summary of work carried out to determine, improve and ensure operational reliability of the Perpetuum PMG17 vibration energy harvester. A full account of this work is recorded in the Reliability Case for the PMG17.

## FMECA

A Failure Mode, Effects and Criticality Analysis was performed by BMT Partners on the PMG17 design. Using standard values for the failure rates of each of the components led to the following predictions:

- Unit Mean-Time-To-Failure (MTTF) of 440 years. This corresponds to a prediction that 2.5% of the population will have fail after 10 years of operation.
- The metal springs and the complete electrical subassembly are predicted to have the highest failure rates.

The prediction made by a FMECA analysis makes the assumption that each of the components is designed "correctly". In order to assess this a series of tests have been (and are continuing to be) performed on the product and its components. Due to the relative importance of the springs and electrical subassembly, tests have been designed to reveal failure modes in these parts. Note that it is not possible to directly "confirm" the predicted failure rates because even the highest MTTF, which is for the spring, is $10^7$ hours.

## Spring Stress Testing

The detailed design and manufacturing methods of the springs have been repeatedly revised and tested. This was done using the spring parts for the 120Hz model as they experience higher stress than the corresponding 100Hz parts. The aim of the exercise was to understand the physics of failure of the springs and to improve their reliability. Excellent correspondence between finite element analysis and high-stress test results has been achieved. The result is a spring part (#26161) that exhibits a repeatable fatigue limit at a deflection of approximately 0.74mm (See Figure 1). A large body of evidence suggests that parts operating below their fatigue limit will not suffer fatigue failure and enjoy "infinite" life. The PMG17 device contains mechanical hard-stops that limit the resonator maximum amplitude to 0.45±0.05mm and in typical use the amplitude will be only 0.05mm to 0.2mm. Hence we expect that the PMG17 springs will exhibit life behaviour consistent with or exceeding the figures used in the FMECA. Work is continuing to develop the region in Figure 1 around the fatigue limit with many more devices.

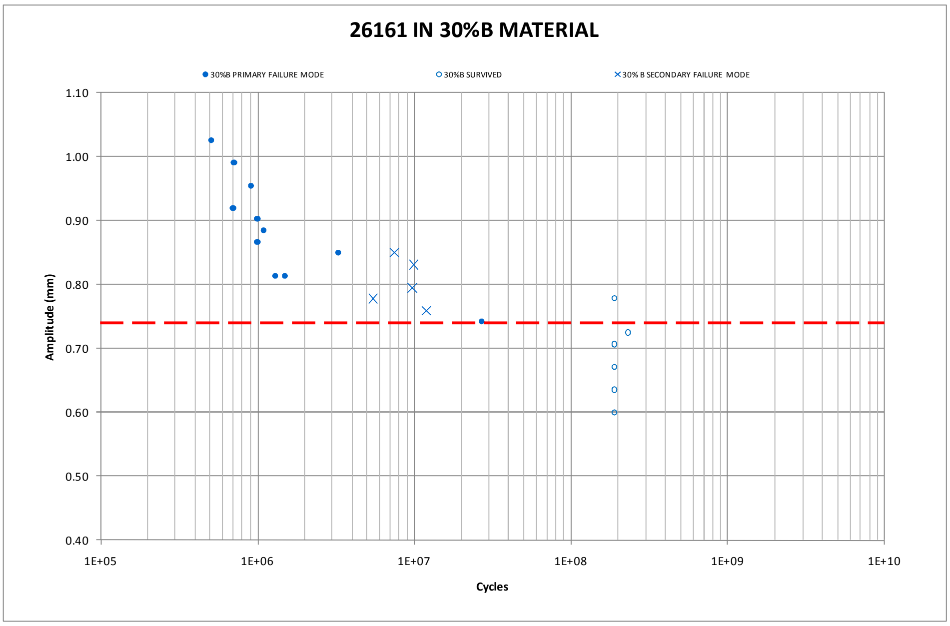


Figure 1. The results of high-amplitude resonator testing on 22 test devices. Two predictable fracture failure modes exist. Surviving devices remain entirely within specification. Lowest amplitude failure at 0.74mm.

Note: Devices have amplitude hard-stop removed for this test.

Key:

- • Fatigue failures
- x Non-fatigue failures
- o Surviving devices

## Electrical Sub-assembly Highly-Accelerated Life Testing

Electrical Subassemblies have been exposed to high vibration accelerations and rapid temperature changes inside a standard Highly-Accelerated Life Test (HALT) chamber at TUV Ltd in Eastleigh. Early tests exposed a weakness in the design which was remedied by changing the plastic moulding process of the wire bobbin. The current build of the subassembly now withstands 25g(RMS) vibration with rapid temperature changes between -50°C to +85°C.

## Sealed, Full-Unit Highly-Accelerated Life Testing

Four PMG17 units have been exposed to HALT (-80°C to +85°C / 40g / 5 cycles) and remained entirely within technical specification.