WEIGHT ON WHEEL SYSTEM BASED ON STRAIN GAUGES

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Abstract

A new Weight on Wheel (WoW) System based on strain gauges has been developed in Airbus Military to improves the WoW Detection System of some landing gears. Usually the landing gears have already implemented a WoW system based on Shock Absorber (SA) stroke movement using inductive sensors to detect the stroke position.
This WoW System was developed to detect a load which was not possible to be detected by the standard WoW system based on inductive sensors. This load is so small for the SA that its stroke position would not have changed.
After some investigation, it was decided to instrument a hollow pin directly related with the load path and the SA. The hollow pin and its bearing arrangement were suitable to be instrumented by standard strain gauge techniques using shear bridges.
Such kind of detection allows shortening of the landing run.

1 General

Typically the WoW system is based on inductive sensors which, depending on the Shock Absorber (SA) displacement, the sensors detect a trigger point which corresponds to a specific load. This load is fully dependent of the behavior and characteristics curves of the SA.

In this project the SA starts to move when the load acting on the wheel is around, let's say, Q KN, with a dispersion of +/- 20% due mainly to its temperature dependent behavior.

The challenge was to find another WoW system with a lower load trigger point and as much as possible, temperature independent.

Also, the final system would be compatible with the existing inductive system. The signal output of the new systems would simulate the inductive signal of the inductive sensors to avoid any change upwards in the whole system.

The new trigger point was fixed to be Q/2 KN (from now on we call it T). This trigger point corresponds approximately to, considering the Aircraft (A/C) Minimum Operational Weight, the following percentages:

10% at 3º attitude and above
20% at 1º attitude
30% at 0º attitude

The above numbers are by themselves a challenge for any aircraft.

Such kind of load detection reduction means that the landing run could be reduced by 200 m.

2 Preliminary Analysis and tests

In the first approach the alternatives were analyzed in two ways:

- Using Stroke detection: S/A curve mod.
    - External pressure vessel
    - Elastic washers
    - Opposite dual S/A
    - Annular chamber
- Not Using S/A stroke detection

- Load detection through Inductance measurement
- S/A bearing load detection
- Stress detection (Bolts, Lugs etc...)

After this analysis it was decided to start to investigate the feasibility of a standard technique used to measure load in bolts by measuring shear stresses with strain gauges. Reason: There was a hollow PIN, just in the load path between the shock absorber and the trailing arm, which seemed to be suitable for measuring the load received by the S/A coming from the wheel.

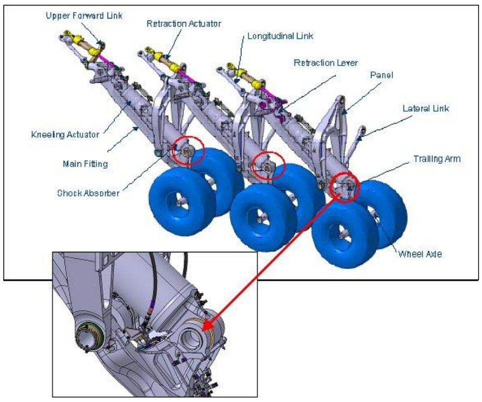


Fig. 1. Pin Position

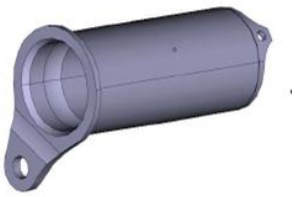


Fig. 2. Typical PIN

The technique, used in the crane industry, use strain gauges located in a gap created to locate the gauges. The bolts used for that show geometry as follows:

Fig. 3. Typical Industrial Load Measuring pin

These kinds of pins have dedicated areas for loading, for reactions and grooves for positioning the gauges.

The Aircraft PIN bearing arrangement was not possible to be modified so the first stage was to check how the shear areas look like and perform preliminary tests to get how the strain gauges answer to the load.

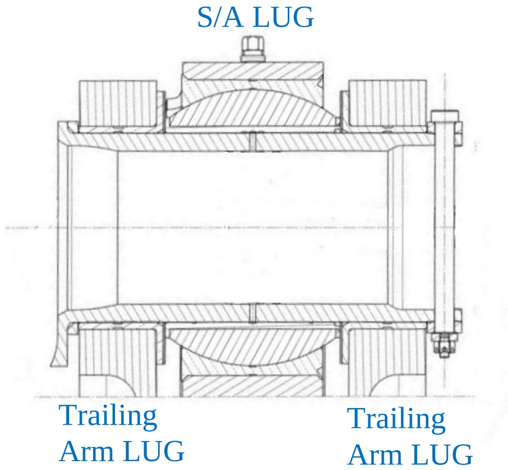


Fig. 4. Current PIN bearing Arrangement

What we were looking to find were areas in which the gauges could be bonded. At the same time, the load and the reactions should keep the same relative position between them in order to obtain repetitive signals.

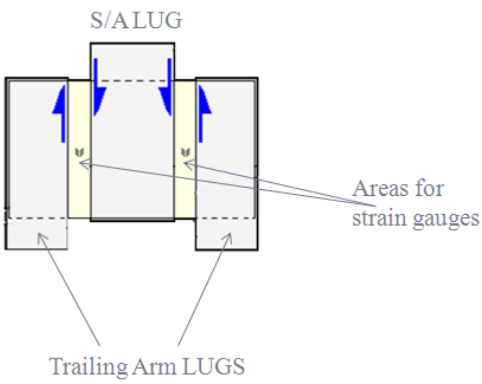


Fig. 5. Areas for instrumentation

The current arrangement show some areas which could be dedicated to the strain gauge location (see Fig. 6).

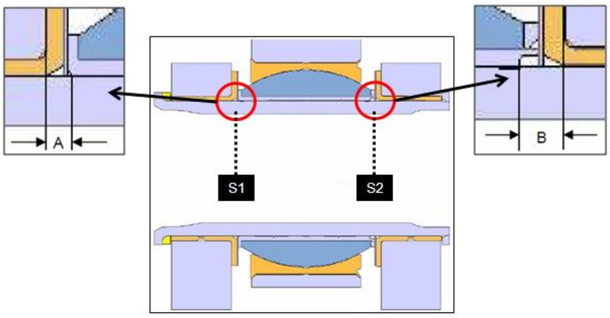


Fig. 6. Instrumentation Areas

Another concern appeared due to the high shear stress in the area. Such kinds of pins are highly stressed and the material is very high yield strength steel. There is no problem for the structural pin itself, but it could be a problem for the strain gauges.

The gauges are typically designed to withstand, without damage and without any fatigue problem 10^8 strain cycles of +/- 1500 µstrain or 0/+2700 µstrain or 0/-2700 µstrain. If the gauges were going to be outside these margins then a fatigue analysis or tests would be needed.

Special care was taken to select the appropriate gauge type, adhesives, protections etc.., in order to accomplish with the specifications given to the equipment:

1) To withstand the complete Service Life, i.e. 30 years, 10.000 flights
2) To be temperature compensated.

3 Load Analysis and S/A behavior

The load applied on the wheel is, a portion of it, reacted by the S/A.

Just in the moment of landing and while the load Q1 is less than T (the desired trigger point, see section 1.), the reaction angle is α. When the load Q1 increases up to Q2, the angle α decreases to β with the S/A law, which is dependent of temperature. See Fig. 7 and 8.

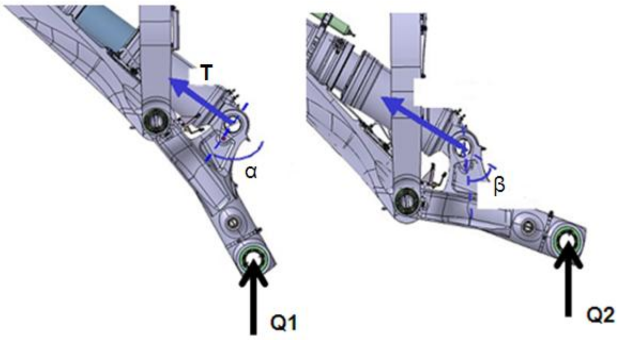


Fig. 7. Load and angle evolution

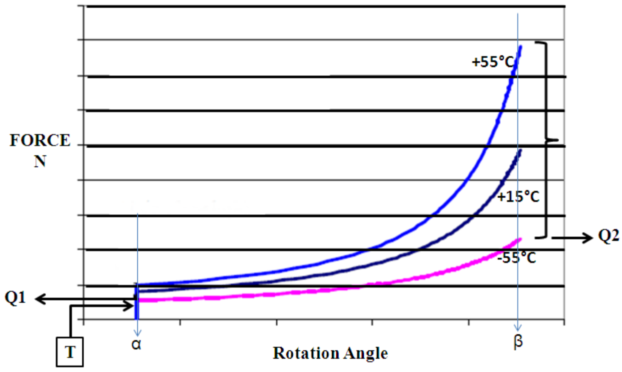


Fig. 8. S/A ISOTHERMAL curves at different Temperatures

After the evaluation of the S/A curves the main objective would be to find some combination of strain gauges (connected as full bridges) which would give an output below the lowest S/A isothermal curve.

If the selected combination would give the same signal output at forces below the lowest S/A isothermal curve, at any angle between α & β, then the objective would be covered.

As it is shown in the Fig. 8, at the angle α, without trailing arm rotation, and consequently no stroke movement of the S/A, the minimum load for starting to rotate is Q1. The trigger load for detecting GROUND was specified to be a 15% under the Q1 value. This will be the T load or triggering load at minimum angle.

4 Basic Instrumentation Design

The basic instrumentation design was to put gauges at 45º orientation for measuring shear in the inner side of the pin and in the sections shown in the Fig. 6., S1 and S2.

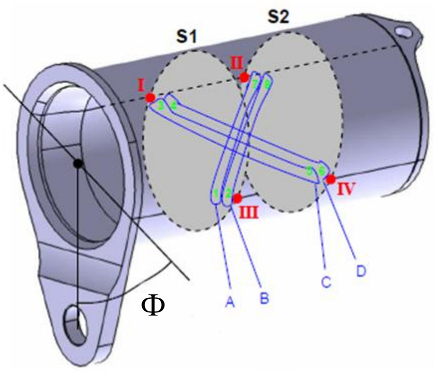


Fig. 9. Basic instrumentation Lay-out

The basic instrumentation takes values of both sections S1 & S2 in order to sense the shear loads at both sections and consequently have a more consistent value. The gauges and bridges were duplicated to obtain a redundant signal as the original inductive system.

The gauges, adhesives, protections etc.., were selected to be temperature compensated, high reliability with fatigue loads and easy wiring between them. Because the wiring can cause errors and temperature drifts a Flexible PCB was designed and bonded inside the PIN to avoid errors and at the same time compensate the wiring lengths and consequently the temperature drifts.

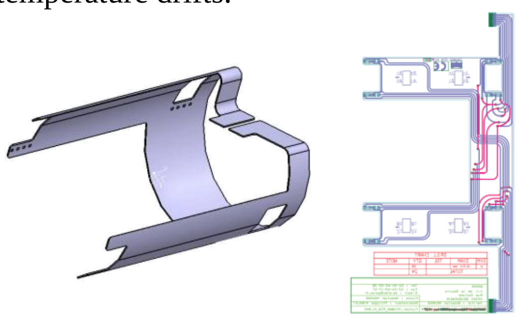


Fig. 10.Flexible PCB

The gauges are then wired to the Flexible PCB instead of wiring between them with wires.

Gauges selected were Module Compensated, 350Ω, WK type with shear pattern configuration.

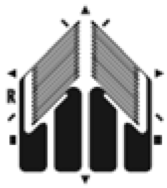


Fig. 11. Shear Pattern Gauge [6]

The typical curve of cycles/strain for gauges (as the S/N curve for materials) is as follows:

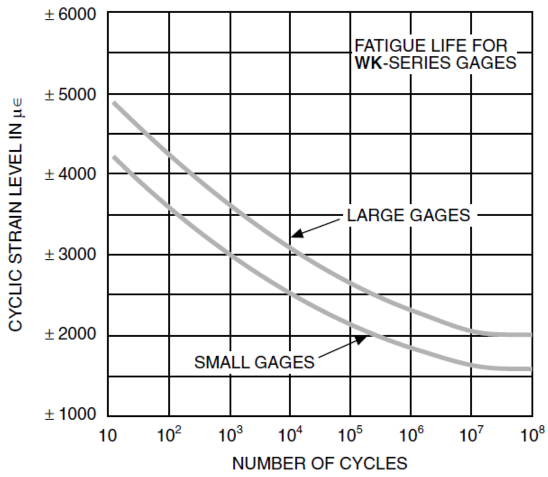


Fig. 12. Micro-Measurements gauge curve [6]

At the beginning, in the preliminary tests the gauges were located at 90º, respect the load direction. After several tests at the highest loads some gauges failed due to the very high strain at that position after a very low number of cycles.

While this is the basic instrumentation, the most important parameter to obtain is the strain gauges positioning angle respect to the load in order to avoid the higher strains under the higher loads. See angle Φ in the Fig. 13. Higher loads appear at higher load rotation angles, closer to angle β (see Fig. 7 & 8.), but at the same time strain gauges should be less sensitive to sense smaller strain values.

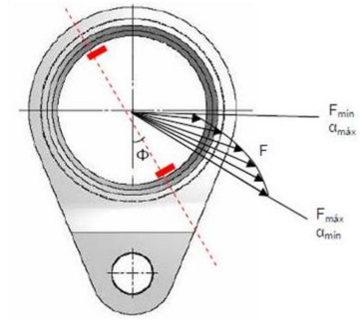
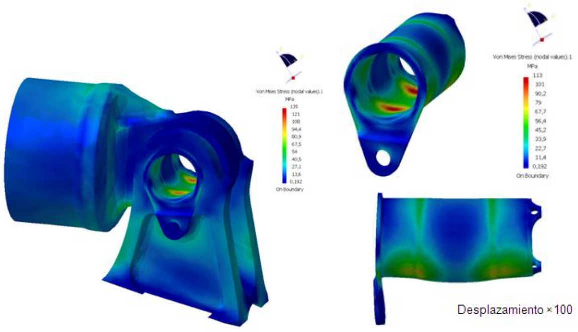


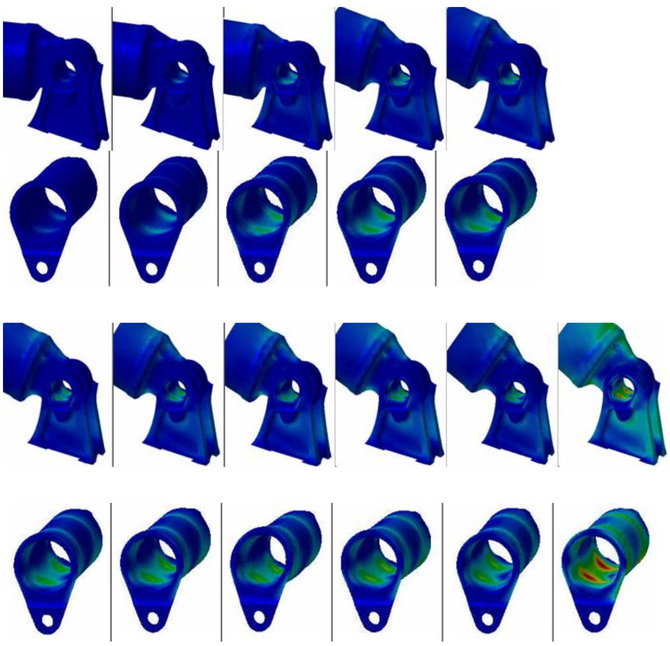
Fig. 13. Strain gauges Positioning Angle

5 FEM analysis

In order to get the best gauge location and at the same time to obtain an appropriate signal level a FEM analysis was implemented.



The analysis at different angles and maximum loads at each angle:



With this analysis it was discarded areas where there could be potential fatigue problems for the gauges and other areas with low bridge signal, invalid to get a reasonable signal/noise ratio.

6 Final Strain Gauges positioning and characterization curve

Finally the Φ angle was fixed and the characterization curve was obtained by test and compared with predictions. The typical characterization curve is shown in the Fig. 14.

The curve for channels P1 and P2 was obtained with A+B/2 and C+D/2, being A, B, C and D the bridges shown in the Fig. 9. The following Fig. 14 show the load triggering values for the same trigger signal obtained at the minimum angle α, and for all the possible angles from α to β for channel P1 and P2.
All the loads over the curve will trigger the GROUND signal in the WoW system. All the loads under the curve will trigger the FLIGHT signal.

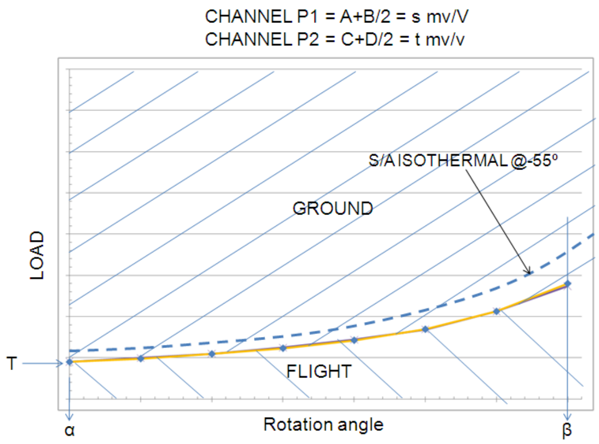


Fig. 14. Characterization Curve

In the Figure 15 is shown all the loads conditions (load spectrum) which can appear in landing maneuvers.

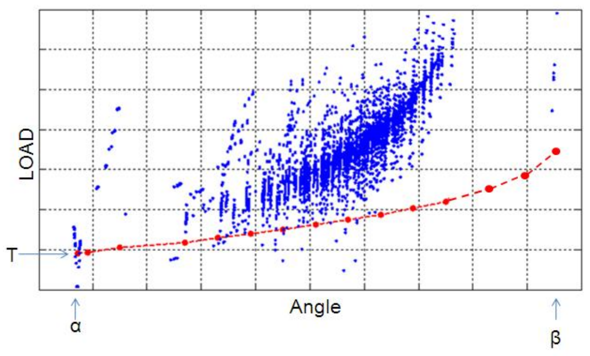


Fig. 15. Spectrum Loads

All the blue load points should trigger the GROUND signal but some of them were located under the characterization curve.
All those load conditions were studied and were found without risk for the aircraft operation.

Depending on the Φ angle, the characterization curve can have a low or high slope rate, mainly in the higher angles. With a low slope rate the answer of the system is better, ideally, the better curve is a horizontal line but it is impossible due to the nonlinearity of the shear distribution. At the same time, as much as the curve has a low slope rate the strain gauges have higher strains because the gauges are moved to the maximum shear angle so it is important to verify with the load spectrum the level of μstrains in order to assure the service life (see Fig. 12).

7 Tests

The tests performed to the Instrumented PIN in the development phase were the following:

- Static tests at different angles to obtain the strain levels at all load conditions.
- Calibration tests to obtain the characterization curve.
- Fatigue tests with a scatter factor of 3 applying the complete spectrum of 3 service lives.

The tests performed to the Complete Equipment in the development phase (Instrumented PIN + Electronics + etc…) for the Certification phase were the following:

- Calibration tests to obtain the characterization curve.
- Fatigue tests with a scatter factor of 3 applying the corresponding spectrum of 1000 flights for being, in first stage, flyable equipment. In a second stage the fatigue test will continue until 10000 flights
- Applicable tests according to EUROCAE ED-14D/TRCA-DO-160D

The Tools used for all the structural tests were found to be very important. The tools have to simulate as close as possible the aircraft interface geometry, including bushes, ball bearing, etc…

Another functional test was performed on a dedicated dynamic RIG.
Such RIG was capable to simulate landings and take-offs at the real frequency, using real aircraft recorded data from FTI parameters.
The RIG was also connected to the aircraft Remote Data Concentrator (RDC) unit in order to check and record when the signal GROUND or FLIGHT appear. At the same time, the load and rotation angle applied was recorded to correlate all the data. See Figs. 16, 17 and 18.

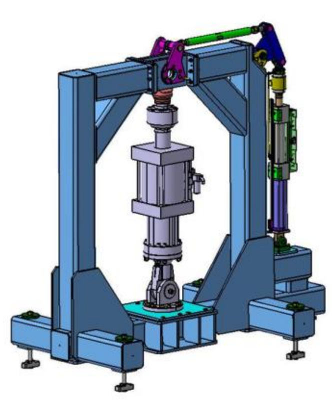


Fig. 16 Dynamic RIG

Fig. 17 A/C RDC

Fig.18. RIG Detail

As a result of the tests the following fig. 19 shows how the load & angle change and when the signal WoW appear as GROUND (ON) or FLIGHT (OFF).

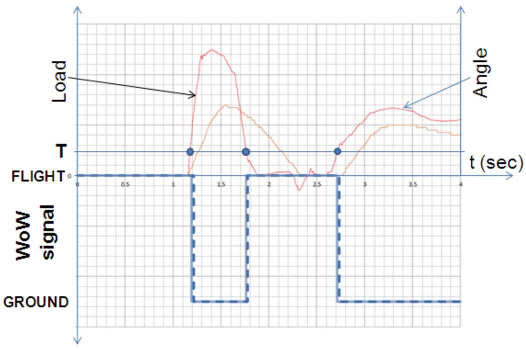


Fig.19.WoW signal versus Load & Rotation Angle

8 Electronics description

The main function of this WoW electronics is to transmit a status output whose value depends on status of the A/C (in flight or on ground).
The system has two independent channels. Each channel has two different strain gauge bridges as inputs. To determine whether A/C is on ground or not, the electronic card uses the average of measurement from both strain gauge bridges.

The output signals are inductive load outputs to substitute the passive proximity sensors. The output values should be:

- In flight: 4.2mH < L < 4.84mH & 20 Ω < R < 40 Ω
- On ground: 5.7mH < L < 7mH & 20 Ω < R < 40 Ω

The system has an internal CBIT (Continues Built In Test), if an error is detected, the output signal is: R > 200 Ω.
A block diagram of this WoW electronic card is shown in the following figure.

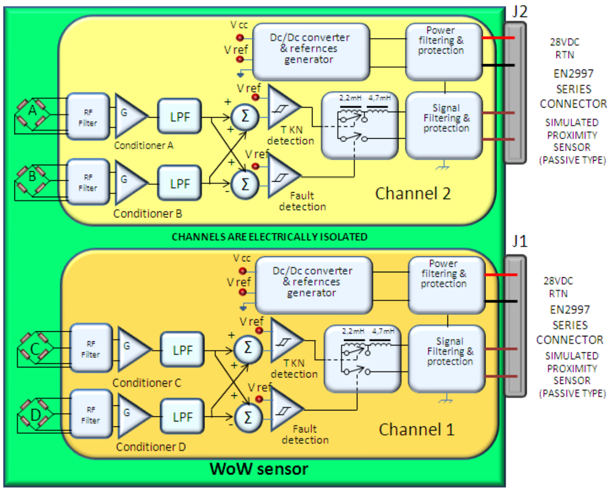


Fig. 20: WoW electronic block diagram.

There are five different modules in this WoW electronic card. These modules are:

1. Signal conditioning module.
2. T KN detection and output module.
3. Fault detection module.
4. Power supply module.
5. Protection modules.

Each module has two identical sets of parts, one per channel.

8.1 Signal conditioning modules

These five modules filter and amplify the signals from the strain gauge bridges with the appropriate gain to obtain a normalized voltage in the threshold load value.

8.2 T KN detection and output module

Adding the two conditioned bridges signals of each channel the mean is obtained to compare with Vref. and determine if greater than T KN through a trigger comparator.
This signal actuates a MOS FET Relay in parallel to an inductor to change the output inductance value.

8.3 Fault detection module

The fault condition is determined by comparing a reference with the signal obtained subtracting the two conditioned bridges signals.
The reference depends on the mean of the two conditioned bridges signals measured. For loads 1.5 times over the on ground / in flight threshold, then the allowed error is increased to assume the dispersion values of the bridges signals.
This signal actuates a MOS FET Relay in serial to the inductors to generate de fail indication making an open circuit.

8.4 Power supply module

The main function is providing a regulated 5V to supply to circuits and bridges, the virtual ground and the voltage references.

8.5 Protection modules

There are two types of protection modules one for the power supply and the other for the output signal and both are designed to protect the circuits for lightning and electromagnetic hazard.

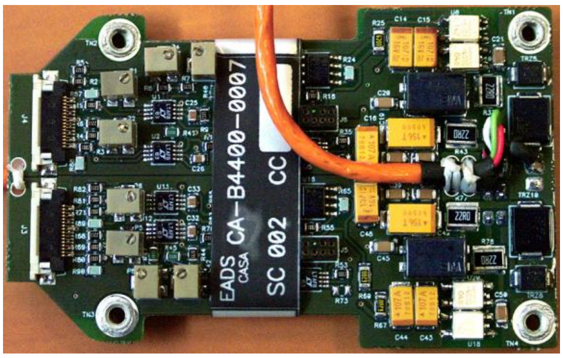


Fig. 21: WoW prototype's electronics

8.6 Measures

It was verified that the output inductions and resistances of this WoW are compliant with those specified for the proximity sensor which is replaced in all range of temperature. Due to the tolerances margin of the inductors it was necessary to make screening to choose the values that fulfilled the requirements.

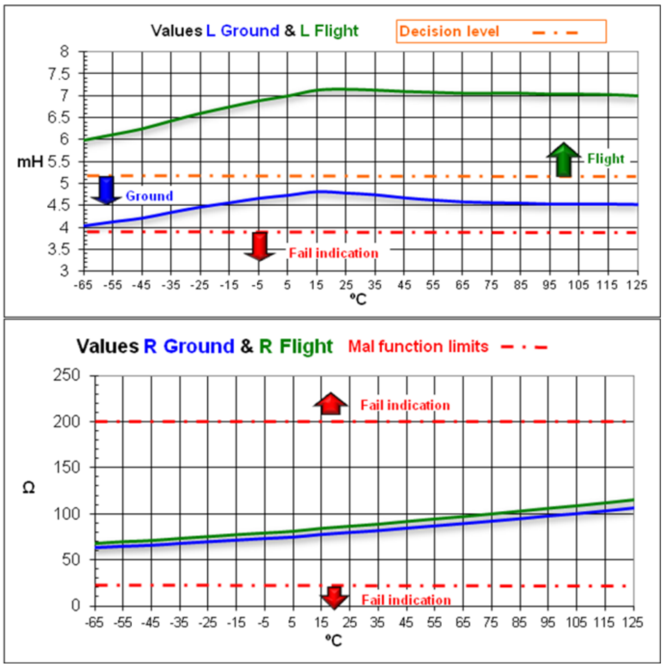


Fig.22: Measured values form L&R versus ºC

9 Evolution

For prototypes the electronic card was part of the final LRU (Line Replaceable Unit) WoW.

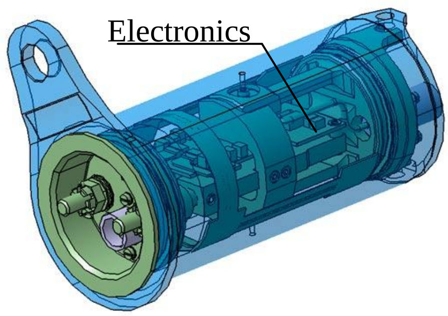


Fig. 23: WoW prototype

In order to improve the reliability of this WoW it has evolved to two LRU, the calibrated pin and the electronic card.
For series, the electronic card and associated components will be an internal LRU to the global WoW system LRU.

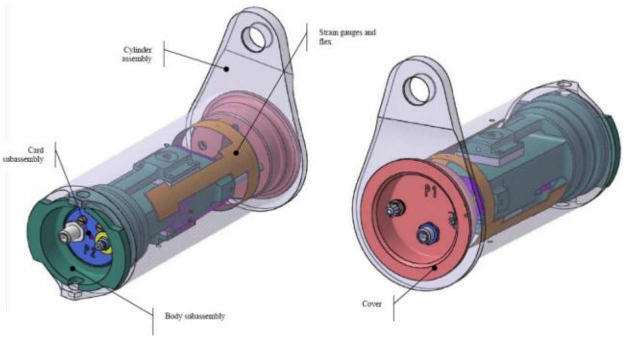


Fig. 24: WoW series.

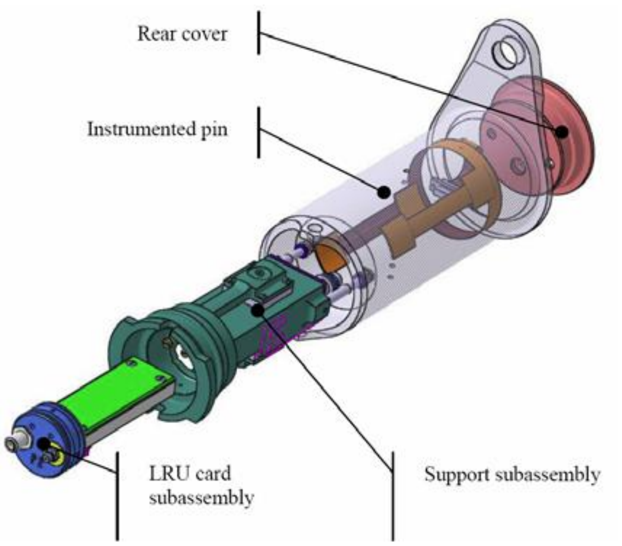


Fig. 25: WoW series explode.

The WoW as global equipment shall have a value MTBF not lower than 75000 OH (Operating Hours) estimated 141000 OH, and the calibrated pin subassembly shall have a MTBF not lower than 128000 OH, estimated 238000 OH.
Also, in the series version an asymmetrical data consolidation filter has been included in order to avoid, as much as possible, undesired transitions in the takeoffs as in the landings.

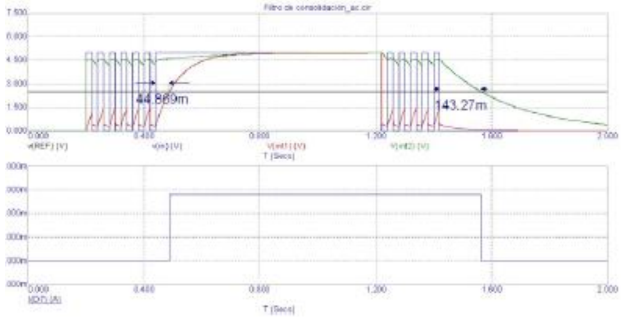


Fig.26: consolidation filter simulation

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[6] Images for Figs. 11 and 12 provided courtesy of Micro-Measurements, a brand of Vishay Precision Group.

Patent

These system/technologies are protected by the following patent applications:
European patent application 10382172.4
International PCT application PCT/EP2011/070425
US patent application 12/869,309

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