EXPERIMENTAL INVESTIGATION OF THE LOAD SPECTRUM AND FATIGUE TESTS OF THE PW-5 WORLD CLASS GLIDER

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Summary:

Matter presented in the paper concerns the research determining operation life of the PW-5 World Class Glider. The investigation was divided in two planes:

A. Records of the glider 's loads in the air and estimation of the load spectrum of the glider,

B. Modeling these loads on the stand for fatigue test of the glider's main structure.

The glider's loads were recorded on the PW-5 glider equipped with digital recorder and deflection-sensor of the wing-spar-root and electronic accelerometer fixed in the glider's gravity center. The load spectrum - was obtained using original data processing briefed in the paper. It was applied to the fatigue tests of the wing-fuselage-set. The paper contains also the description of the original resonance electrodynamic load method and remarks from the present stage of the research.

Introduction

One of the main aims for the PW-S designers team after successful tests in flight of the sailplane prototype was to prove the operation life of 9000 hours required by the rules for the World Class glider and to arrange the fatigue tests of the main structure of the sailplane. Those tests were divided in three stages.

The first stage was fatigue test of the main joints.

The second stage concerned fatigue tests of the central part of the wing-spar together with the wing-spar-root which are the most loaded parts of the sailplane structure. During the tests the wing-spar was proved for 27 thousand hours of simulated flight. Such a big quantity of test-hours comes from the technical requirements concerning the multiply-factor of the load cycles equals 3 in the case when the tests are done only with one specimen but the results are intended to apply to whole statistic population of the PW-5 gliders.

The third stage concerns complex fatigue tests of the wings-fuselage-set and the joints existing there. This is now going on.

Main aims of these investigations are:

A. Estimation of the load spectrum of the glider,

B. Simulation of this spectrum on the fatigue-test stand.

Estimation of the load spectrum of the glider

The load spectrum is the base of the fatigue tests. It describes the amplitude of the variation of the load factor **n** and the number of cycles N for given amplitude for specified period of the glider's exploitation. It is based on the records of the glider's load factor in different states of flight or it may be also a result of load factor estimation and statistic analysis concerning the number of load cycles.

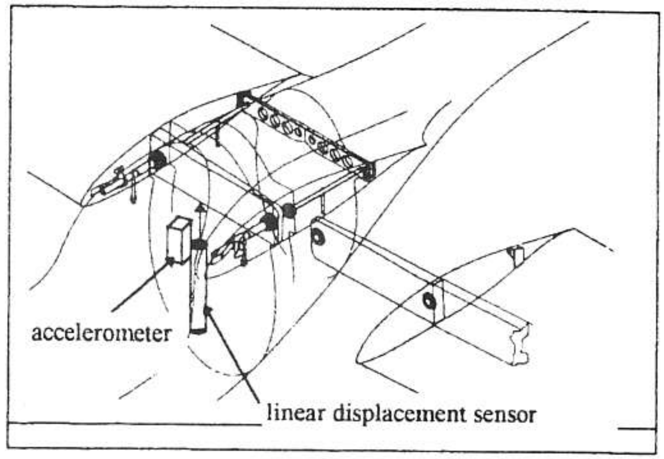

Figure 1. The idea of wing-fuselage connection and position of sensors used for load-factor measurement.

The elaboration of the load spectrum of the PW-5 glider was related to the load spectrum of another glider. It was SZD-5 1 "Junior" - the glider very similar to the PW-5, which was designed and tested a few years earlier.

The load spectrum of this glider consists of 11 blocks of load cycles (BLC) which relate to specified states of exploitation. There are singled out the sets of cycles (SC) with

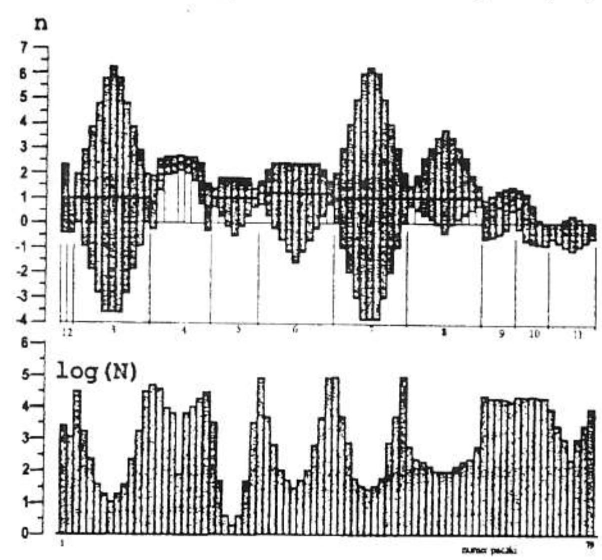

Figure 1. The load spectrum of the glider (blocks of loads related to exploitation) state:

1. *Winch-towing*
2. *Aerotowing*
3. *Gusts during aerotowing*
4. *Gusts during winch-towing*
5. *Basic training flights*
6. *Gusts during thermaling*
7. *Gusts during intercurrent flight*
8. *Basic aerobatics*
9. *Ground-run during take-off*
10. *Ground-run during landing*
11. *Taxying on the ground*

equal amplitude of the load factor. The sum of the cycles for all BLCs in relation to 1000 hours of exploitation is near 900, 000.

The modification of described spectrum which took place in early stage of the elaboration of the load spectrum for PW-5 relies on the limitation of the N_{max} and N_{min} in to the values appropriated for PW-5 - without any changes related to exploitation states and number of load cycles. The spectrum acquired in this way is shown in the Fig. 3. The sequence of the BLCs is the same as in the Fig. 2 but for better expression of the quantity proportion of each SCs there was applied linear N-ax. Such spectrum is an input to the further investigation of the fatigue properties of the PW-5.

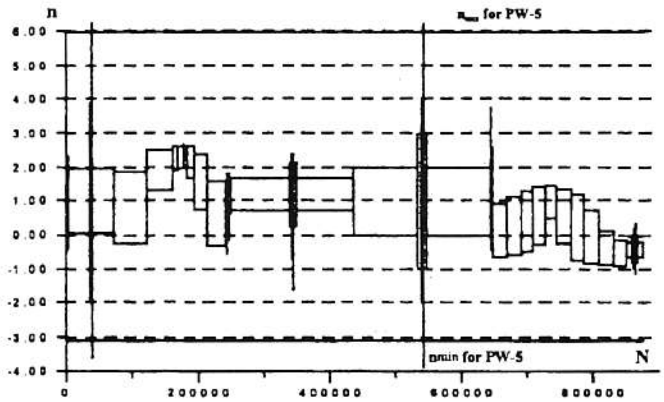

Figure 3. The load spectrum of the SZD-51 "Junior" and "PW-5" 'Smyk' for 1,000 hours of exploitation.

For verification of this spectrum - one PW-5 glider was equipped with the digital recorder and with two sensors: the sensor of the of the wing-spar root middle point displacement (Linear Transducer - LD) and electronic accelerometer fixed in the glider's gravity center.

The DL allows for estimating the value of the bending momentum at the wing-spar-root. The accelerometer allows to estimate the value of the load factor.

Furthermore, the glider was equipped with GPS Garmin 12XL and electronic barograph made by Flytec which allow recording the trajectory of the flight. The sample of the recorded signals is displayed in the Fig. 4 & 5.

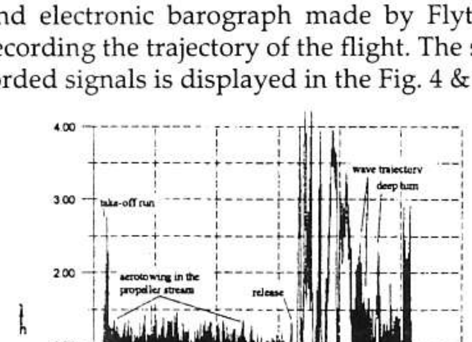

Figure 4 . Run of the load factor in the flight aerobatics.

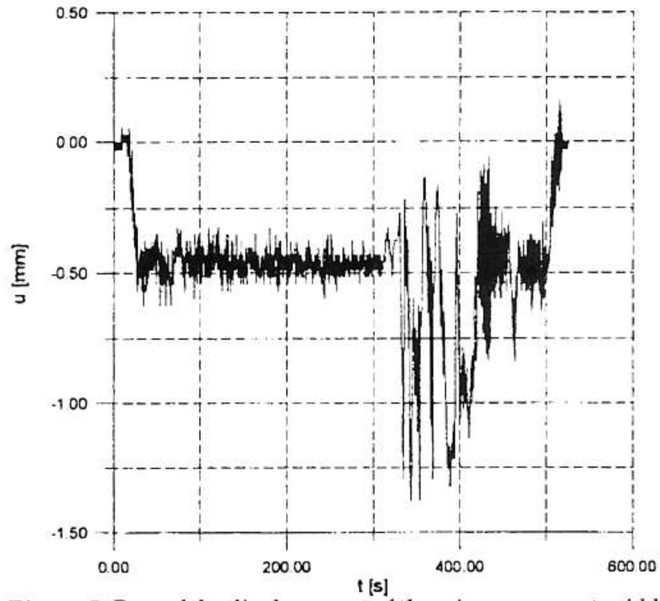

Figure 5. Run of the displacement of the wing-spar-root middle point for the flight from Figure 4.

The signals are recorded in 8-bits and 20 Hz mode (256 levels of measured signal range.) Another ability of the digital recording technique applied in the PW-5's investigation are displayed in figure 6 with the prints from the GPS.

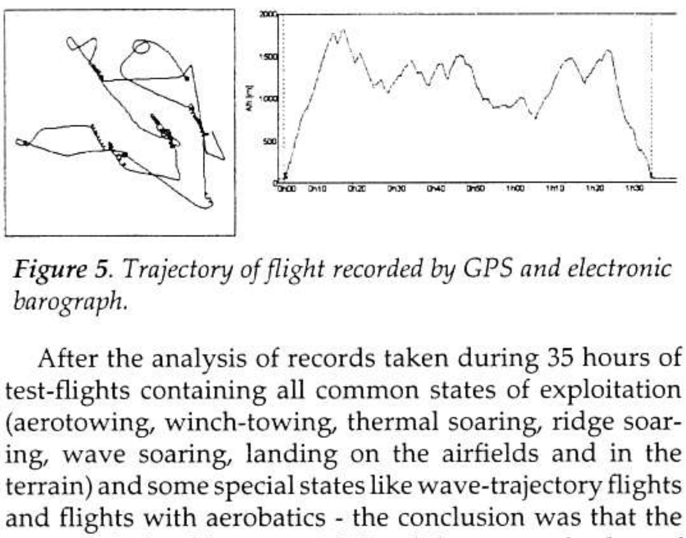

Figure 5. Trajectory of flight recorded by GPS and electronic barograph.

After the analysis of records taken during 35 hours of test-flights containing all common states of exploitation (aerotowing, winch-towing, thermal soaring, ridge soaring, wave soaring, landing on the airfields and in the terrain) and some special states like wave-trajectory flights and flights with aerobatics - the conclusion was that the range of the load factor variability did not exceed values of -3 and +6 and that the range of the wing-spar-root middle point displacement is from -1.12 mm (for **n**=-3) to +1.40 mm (for **n**=6). In the case of negative loading the loads during landings have major influence.

The analysis shows good correlation of the acceleration and displacement signals in all stages of flight excluding ground running during take-off and landing and during winch towing. For this reason, the signal of the middle point of the wing-spar-root displacement was recognized as the most representative for the loads-analysis although the technical realization is more difficult then the measuring of the acceleration in the gravity center of the sailplane.

The runs of the signals shown in the Fig. 4 & 5 are raw and should be processed. The basic steps of this processing are:

- Filtering the signals,
- Searching for the local extremes,
- Sorting the signal increment in the load-blocks.

The sequence of signal's processing is shown in the Fig. 7.

When sorting the signal increments into the load-blocks - all range of the displacement values was divided into 16 levels. This number was chosen due to reason that the total number of the loading blocks after sorting should not be too large to be easily simulated on the glider's fatigue stand. The result of sorting is presented as the drawing showing the

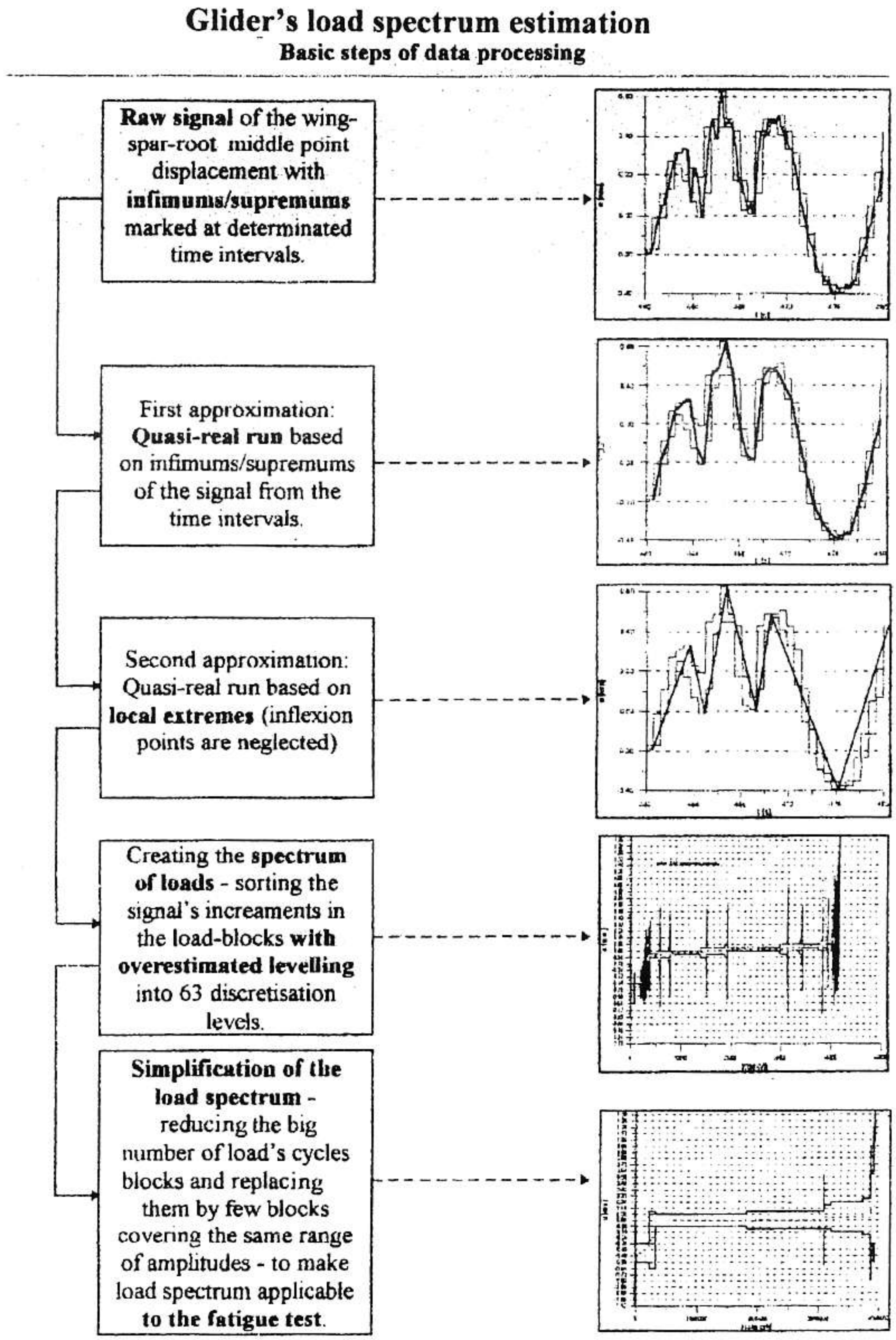

Figure 7. Scheam of the data processing used for load-spectrum estimation.

blocks of displacements cycles, put in order according to their average values. This is the output of data processing shown in the Fig. 7. This output is upgraded after each series of flights.

The spectrum obtained in such a way is used for verification of the initial version of the load-spectrum used for fatigue tests.

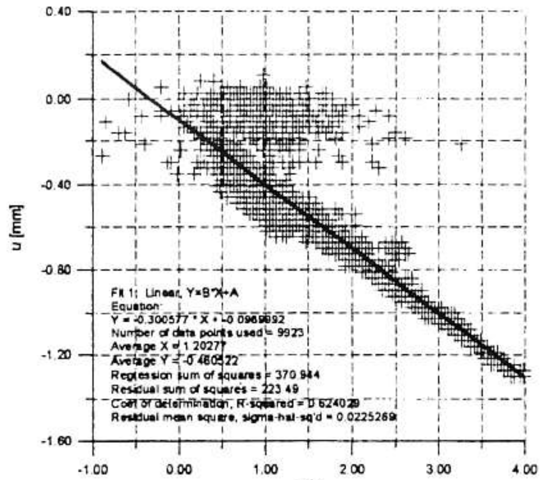

Figure 8. Relation between increments of the wing-spar-root displacement and CG-acceleration (flight with aerobatics).

Fig. 8 shows the relation between the increments of the wing-spar-root displacement signal and the gravity center acceleration signal which were related to the values corresponding to steady straight flight (n=l). It is visible that only small groups of the points are far away from the straight line approximated on the collection of registered points. They are exactly the groups of points recorded during ground phase, take-off and landings.

The slope of this straight line estimated on the ensemble of points (excluding take-off and landings cases) is a useful parameter for verification of the loads-simulation quality on the fatigue stand by comparing it with the same parameter taken from this stand.

Realization of the fatigue-tests

In both cases of fatigue-tests (wing-spar-root fatigue test) and of the wings-fuselage-set fatigue tests) the basic method of load-realization was bending oscillation of the resonance type excited by a special electrodynamic synchronized activator. For this purpose special oscillation systems were built based on the bending stiffness of the wing-spar (lst case) or on the bending stiffness of the wings-fuselage-set (2nd case). The system used for the fatigue test of the wings-fuselage-set is displayed in the Fig. 10.

The wings-fuselage set hung on the wings at the points of resultant aerodynamic forces. The fuselage is fixed to movable frame. Depending on the parameters of the block of load cycles - this frame is additionally loaded by the pack of the plate-loads. It allows the realization of the initial bending referring to the average value of the load-factor

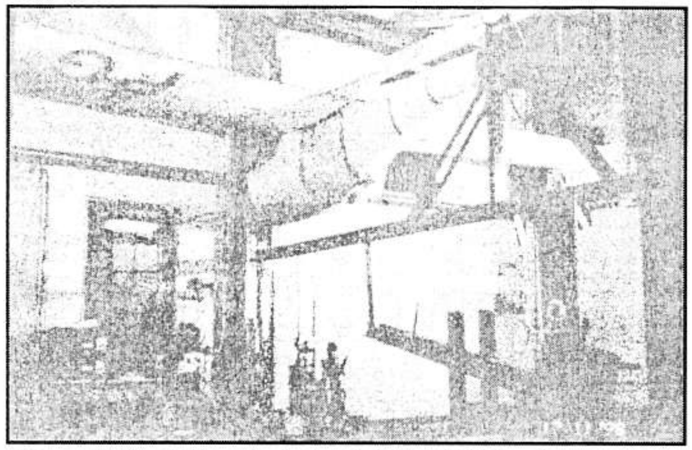

Figure 9. the fatigue-test-stand of the PW-5's wings-fuselage-set.

for given block of loads cycles. This also locates the suspension points of the roots of electromagnets exciting bending oscillations of the wing-spar.

There are two main subsystems: lst – A set of electrodynamic synchronized activator (author's patent No PL 176320 Bl). It contains the electromagnet supplied by system consisting of the current-key and the controller coupled with wing-spar movement detector.

Due to existence of this feedback - the wing-spar is excited to oscillate by magneto-force impulses given exactly in the certain phase of the movement, independent from the changes of the self-oscillation involved by temperature changes or by fatigue-effect.

The amplitude of oscillations is controlled by the width (time) of electrodynamic impulse and is set by the potentiometer on the board of the controller. Additionally the system is equipped with the impulse-counter.

The second subsystem of the fatigue-stand is the measuring/recording system which consists of sensor of the wing-spar-root middle-point displacement and the digital-recorder.

Conclusions from the present stage of research

1.The realization of the tests unmasked that the main problem of the load-spectrum investigation is acquisition of flight-data in the digital-recorder and available time of recording. In spite of the fact that the frequency of the 1st mode of natural frequency of the wings-bending oscillation is about 1.5 Hz, it is necessary to use a recording frequency not less then 16 Hz to avoid the lost of momentary extreme wing-spar-root deformation (involved for example by turbulence). With 8-bits resolution of the signal (what seems to be minimum acceptable value) - it causes quick consumption of the digital-memory (one hour in case of DALI 2 recorder, when two channels in use). The problem is important during cross-country flights, when other methods of data acquisition are difficult to apply. For this reason and specially for load-spectrum investigation - a new system of data acquisition was introduced in which the AC-converter works with higher sampling frequency (in between the range: 32 ÷ 64 Hz) and with

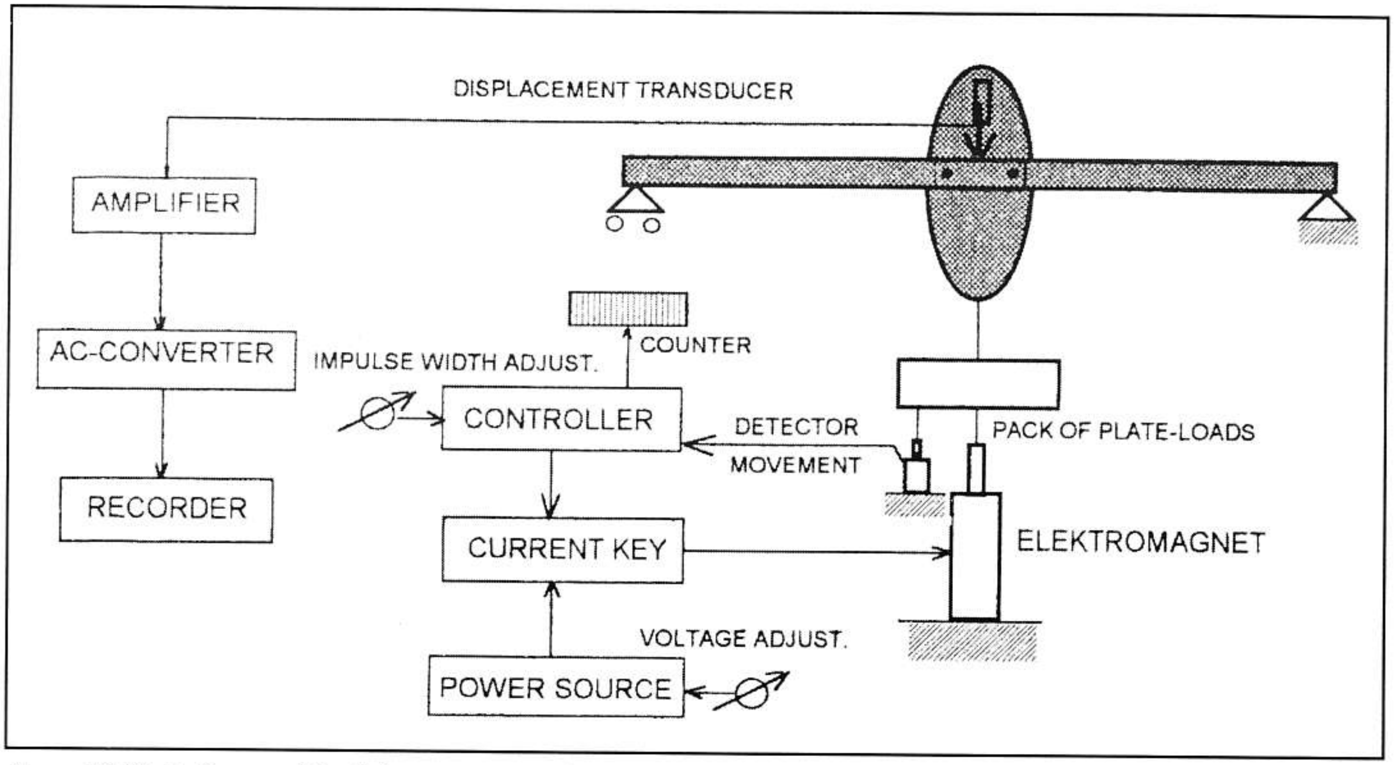

Figure 10.Block-diagram of the fatigue test system based on resonance method.

12-bits resolution but only extreme values from period n-times longer then sampling interval are stored in the memory (the range of record-interval is between 0.5 ÷ 2 sec). Such a system allows extended time recording without enlarging the memory (caused high cost!) and/or weight & size of the recorder.

2. The system of loads used in the fatigue tests is very effective. Due to resonance type of the oscillation only small power is necessary for the fatigue-test, compared to the power-consuming method with classic hydraulic fatigue-systems. For example the realization of the fatigue cycles in the range of **n**=0 to **n**=2 needs about. 0.5 kW. The other advantage of the system is a fact that the bending frequency of the tested object is close to the values taking place in the natural conditions. This is important due to the rheological characteristics of the composite used for the glider's structure. The only disadvantage is the limit of the amplitude of load cycles Δ**n**=4, but only 4% of the cycles exceed this amplitude. Those blocks of cycles are realized with other methods (especially hydraulic methods). The approximated time of realization of the all load cycles for 3,000 hours of simulated exploitation on the stand (equivalent for 1,000 hours of proven operation life of the glider) is about 57 days.

3. Another observation concerns the tribologic effect. There was observed much quicker fretting of steel sleeves and bolts existing in the joins of the wings-fuselage connection than occurs in natural exploitation. The problem is caused by long blocks of constant amplitude cycles. It results in squeezing out the lubricant from the sleeve/bolt contact surface and its accumulation on the opposite surfaces. The solution for it is more frequent simulation of landings (due to obtain negative load factor), which allows lubricant circulation around the pin - similarly like in natural conditions.

References

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