

LANDING GEAR DYNAMIC TESTS WITH STRAIN GAGES

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Abstract

Strain gage sensing is widely used method for measurements conducted during dynamic tests. This article describes electrical resistance strain gages performing force measurement during the tests of main and nose landing gear of medium-lift civil aircraft. It is the most common method used for measuring mechanical properties like force, pressure, stress, strain, etc. Strain gages were installed in selected areas of the Drop Test Stand. The paper presents advantages of strain gage measuring method in regards to commercially available, ready-made force sensors. Furthermore, it describes the process of selecting strain gage and load cell measurement systems (bridge, half bridge, quarter bridge) and its influence on the test results. What is more the technological process is presented, taking into account the strain gage installation adhesive technology and sensor protection against external conditions, performance of the measurement system and connection to the data acquisition system. Continuing with the process description of calibrating a load cell system for measuring the occurring forces. The article is summed up with an analysis of the problems which arise during the installation and measurement process using strain gages, and includes a description of advantages and disadvantages that occur while applying strain gages while performing force measurement

Keywords: *landing gear test, dynamic test, load measurement, strain gage instrumentation, strain gage installation*

1. Introduction

Institute of Aviation's Landing Gear Laboratory is engaged in research both complete landing gears as well as its parts, components and other energy-absorbing materials and structures [4]. As part of the design work there were designed many components including landing gears, braking systems (including anti-locking brake system), [7] test rigs with instrumentation [5]. The most common test carried out in laboratory in order to confirm landing gear compliance with the aviation regulations requirements is drop test. The most commonly used test method is a free fall drop of landing gear fixed to the carriage with lift force generation opposite to free fall direction. It is a proven technique used successfully for many years, allowing very accurate reproduction of the actual conditions of landing [6]. For the measurement of the ground, reactions it is used a strain gauge plate located on the substrate. In this article, the authors present a different approach to drop test, dictated by customer requirements.

The requirements for force, torque and pressure transducers to be made is usually the result of very special measurement problems or installation circumstances which make it appear to be difficult or maybe impossible to utilize standard commercially available transducers. In many cases, certain specific requirements take precedence over accuracy [1].

The Landing Gear is a system composed by three landing gears (right hand, left hand and nose) which function is support the loads generated in the Landing Gear of the aircraft, absorbing the impacts generated on it by means of shock absorbers.

Landing gear compliance with the aviation regulation requirements can be shown dynamically by drop test. The objective of this test is to demonstrate structural adequacy of the landing gear,

demonstrate the L/G energy absorption and to show peak loads resulting from the tests do not exceed the analytical design loads [6].

In such case, ground load components must be measured in order to ensure that limit loads are not exceeded. One of the measurement method is the use of strain gage sensors to measure the forces in the nodes corresponding to each component of reaction forces. Measurements can be made using strain gage installed on the measuring plate on a substrate or by means of pull rods fixing the landing gear to the drop carriage. In the presented project, ground plate was made of concrete, so the measurements were made using the second method.

2. Strain gage installation

The strain gage measures the deformation as a change in electrical resistance, which is a measure of the strain and consequently forces. A load cell usually is composed of four strain gages in a Wheatstone bridge configuration. There is possibility to create load cell using one strain gage (quarter bridge) or configuration of two strain gages (half bridge). Most common is full bridge because of the best temperature compensation, the most accurate indication and obtaining maximum sensitivity. Temperature Compensation is provided by the use of compensation strain gages or by installing the strain gage in the direction opposite to the direction of the force. The above-mentioned factors caused the use of full bridges on the test stand [2].

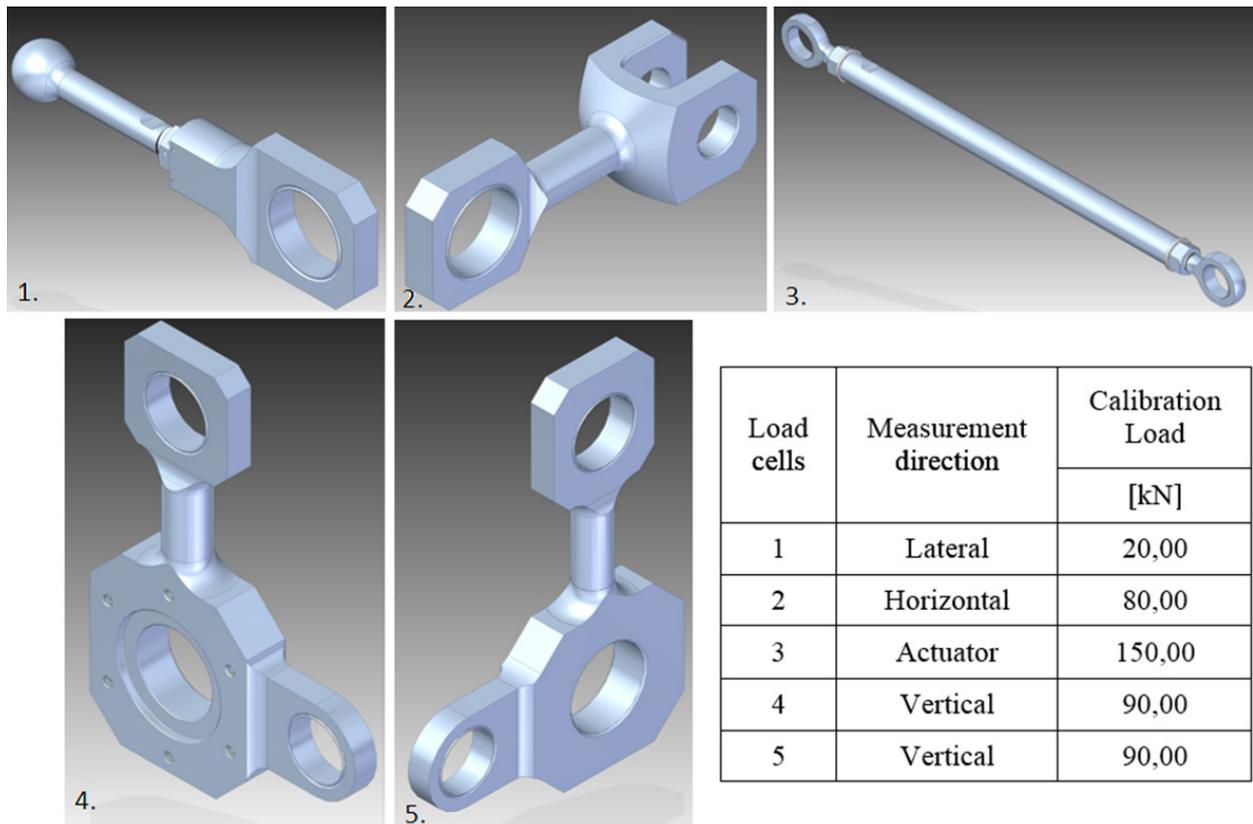
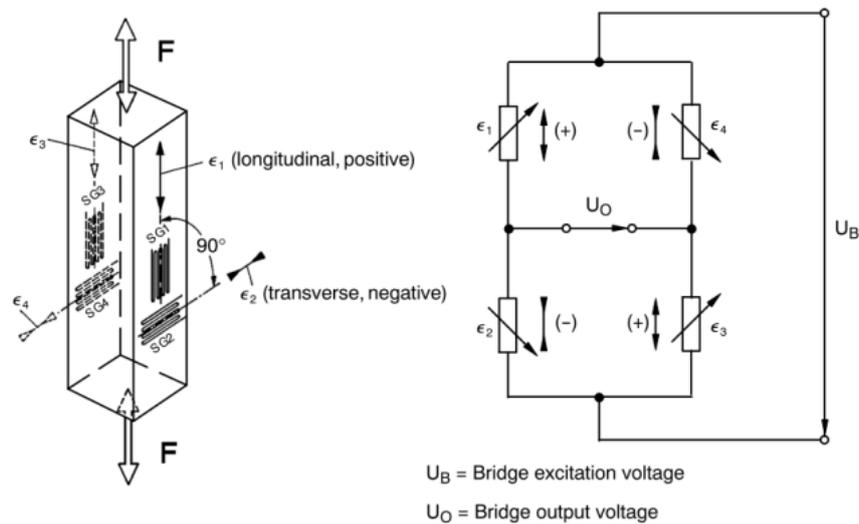


Fig. 1. Structural elements of test stand, where strain gage bridges were installed

The electrical signal output is in the range of a few millivolts and requires amplification before it can be used. In our case, the output of the transducer was scaled to indicate the force during the tests. Major benefits of using load cells are having good resonance values and long life cycles. When weight is applied, the strain changes the electrical resistance of the gages proportionally to the load.

During the tests were recorded following loads:

- Load Cell 1: measures vertical loads on side 1,
- Load Cell 2: measures vertical loads on side 2,
- Load Cell 3: measures lateral loads in Y direction,
- Load Cell 4: measures horizontal loads in X direction on side 1,
- Load Cell 5: measures horizontal loads in X direction on side 2,
- Load Cell 6: measures loads in Actuator direction.



$$\frac{U_O}{U_B} = \frac{k}{4} \cdot (\epsilon_1 - \epsilon_2 + \epsilon_3 - \epsilon_4) \quad (1)$$

Fig. 2. Schematic diagram and Basic circuit of a device for measuring force. When weight is applied, the strain changes the electrical resistance of the gages in proportion to the load [1].

Strain gage force sensors, especially resistance strain gages are most common used in laboratory measurements because of high sensitivity, accuracy of measurements and small size. They are resistant to vibration and shock, can operate at high temperatures and pressures, and be placed on curved surfaces – that makes them best choice for dynamic test [3].

For measuring forces applied to structural elements of the test stand commercially available, ready-made force sensors or install strain gage measuring systems can be used. The main advantage of using strain gage measurement systems is to reduce the cost of the test stand. Does not require special connectors to mount produced force sensors. Strain gages, wiring, glues and other substances used in installation are cheaper than strain gage force sensor. The disadvantage is large workload and precision required for the installation process. There are two methods of installation of the strain gage depending on the kind of adhesive (cyanoacrylate adhesive or a thermosetting adhesive), cheaper and faster method is to use fast-drying adhesive.

Strain gages installation with cyanoacrylate adhesive is a process that requires precision and accuracy. Correct bonding process is a prerequisite for the proper functioning of the strain gage. The first step of strain gage installation is surface preparation. In our case, we consider metal surface. Firstly, the surfaces must be clean of contaminants with solvent. Preliminary abrade surfaces with 200-300-grit silicon-carbide paper and final abrading is done by using 300-400-grit silicon-carbide paper in two perpendicular directions. Then degrease the strain gages area with solvent, such as AK-231. All degreasing should be done with uncontaminated solvent using cellulose swab in “one-way” direction and only one-time. Apply the drop of Neutralizer AOC-211, spread evenly using a piece of Teflon tape and leave to dry. With a 4H pencil or ballpoint pen burnish (do not scribe) – alignment marks are needed on the specimen. In order to precisely position the strain gage in a certain place, we need prepared axial marks and transparent adhesive

tape. On the top side of the strain gage, stick a piece of adhesive tape. The tape with the strain gage stick on the selected location in such a manner that the strain gage marks coincides with the previously marked axes. Then slightly using a tweezers peel off one end of the tape and raise up with a strain gage. Using a piece of Teflon tape distributes equally on the surface of the strain gage slight amount of adhesive cyanoacrylate. Stick the tape with strain gage by the piece of Teflon tape pressed against with your finger to remove the excess glue. The pressure should be steady on the entire surface of the strain gage and take 15-20 seconds (Fig. 3). After several minutes, carefully peel off the adhesive tape. For many types of strain gages, instrument wires generally should not be attached directly to the solder tabs of the gage. Instead, the normal practice is to install bondable terminals adjacent to the gage, and solder the instrument wires to these (Fig. 4).



Fig. 3. Strain gage measurement systems without protection against mechanical damage

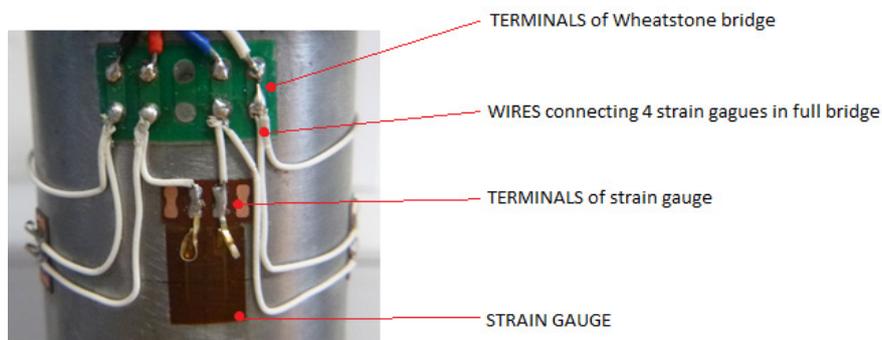


Fig. 4. Strain gage bonded to the structural member

Due to the fragile structure of the strain gage, it should be protected in proper way, matched to the conditions of tests. For laboratory tests we usually use electroinsulating coating protection, in the case of dynamic tests it is necessary to use silicone agents or shielding, adhesive tape with rubber layer. Provided protection against adverse effect of weather conditions and mechanical damage. Strain gage measurements can be performed after 24 hours of sensors installation process.

Due to the strictly definite direction of the force selected unidirectional strain gages. In consideration of test stand's structural elements size it was necessary to choose the strain gages in two sizes (strain sensitive pattern 3.0 [mm] and 1.0 [mm]). In the full bridges used to measure the force on test stand two active strain gages were used, which were installed on construction in the direction of acting force and two compensating strain gages, which compensated the impact of weather conditions (temperature, humidity) and other factors not associated with increased loads.

The materials of which made it strain gages is:

- constantan – in the case of measuring grid (strain pattern),
- epoxy-phenolic resin – supporting pad.

Regardless of the size, strain gages were able to measure the maximum distortion – 4%.

The advantages of applying strain gages:

- high sensitivity and measurement accuracy,
- possibility to use for difficult access areas and on movable machine parts,
- possibility of static and dynamic measurements,
- possibility to use for analysis of biaxial stress state by using strain gage rosettes.

Disadvantages of strain gages sensors:

- susceptibility to temperature and humidity,
- one-time use (strain gage installed in one place can't be use for measurement in other point),
- a relatively long time to prepare measurements – high workload.

3. Load Cells calibration

In the described project, loads were measured as ground reactions in the directions of vertical, horizontal and lateral direction. Strain gage force sensors cooperate with amplifiers generating sufficient excitation to the bridge and measure the resistance changes with the desired precision. Amplifier, which was used, is HBM MGC series, which is characterized by high measuring accuracy and an extensive range of additional functions such as signal filtering, triggering, signal conditioning output, and more. The National Instruments data acquisition hardware and software is capable of recording data at up to 250 kS/s and subsequent data analysis. The configuration of measuring chains is shown in the following diagram (Fig. 5).

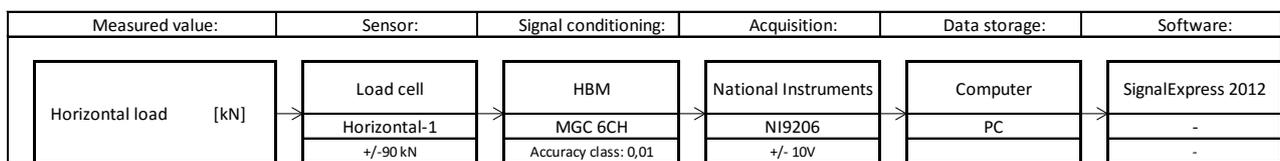


Fig. 5. Load cells measurement chain

The next step for the prepared measuring circuits was to carry out calibration. Load cells were installed on the testing machine for the calibration procedure in compression and tension forces. Based on the collected measurement data the characteristics of load cells, errors and calibration uncertainty were evaluated. The example results of Load Cells calibration are shown in Tab. 1.

Tab. 1. Load cell calibration results

No.	Reference [kN]	Measurement [kN]	Error [kN]	Uncertainty [kN]
1	0.00	0.06	0.06	0.04
2	-20.00	-20.03	-0.03	0.11
3	-40.00	-40.05	-0.05	0.14
4	-60.00	-60.06	-0.06	0.15
5	-80.00	-79.98	0.02	0.08
6	-85.00	-84.94	0.09	0.06
7	0.00	0.11	0.11	0.15
8	20.00	19.97	-0.03	0.09
9	40.00	39.86	-0.14	0.23
10	60.00	59.96	-0.04	0.10
11	80.00	80.02	0.02	0.09
12	85.00	85.09	0.09	0.08

Designed and manufactured at the Institute of Aviation in Warsaw load cells are characterized by high measuring accuracy, small deviations from the reference value and a low level of uncertainty associated with measurements. It has been proven by repeating measurements many times in a controlled environment.

They were also tests made using two measurement systems. The first one consisted of manufactured load cells installed in the nodes landing gear attachment to the carriage frame. In order to perform measurements of ground reaction measurement was tarred with landing gear hanging.

The second measuring system was the strain gauge plate placed on the substrate. Recorded values directly correspond to the ground load reactions in the vertical and in horizontal direction. Fig. 6. Shows comparison of the vertical ground reactions measurements.

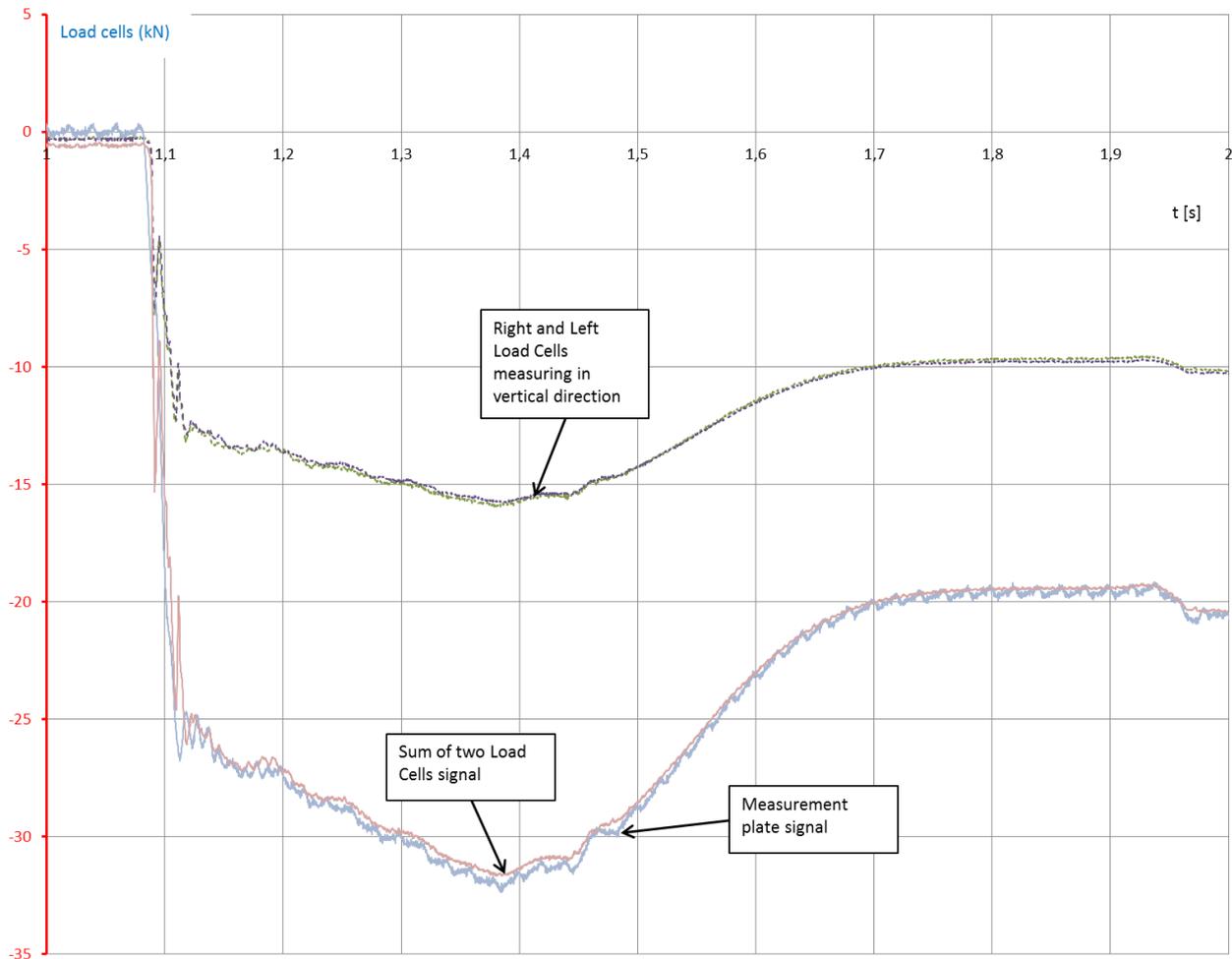


Fig. 6. Test results with two different measurement techniques

4. Conclusions

Strain gage principle combines a number of advantages that predestine its incorporation in measurement transducers, which are listed below:

- excellent linearity, hysteresis, reproducibility and accuracy,
- forces and variables, which can result in changes in force, can be measured in both positive and negative directions,
- static and dynamic process can be monitored,
- the negligible mass of the SG permits very high limit frequencies of measured quantity,
- the good fatigue characteristics of the SG ensure a long life under alternation loads,
- theoretically, there is no upper range limit for measured values.

- high long-term stability,
- SG transducers can be used over wide temperature range,
- small dimensions of the SG assist in the search for constantly smaller size,
- wide range of choice in relation to associated amplifiers allows flexibility.

As it was shown in calibration and test results designed and manufactured load cells are characterised by high accuracy, repeatability and linearity. The same test performed using two different measurement methods shows convergence in obtained results (Tab 2.). Described solution was used successfully during medium-lift civil aircraft landing gear dynamic tests.

Tab. 2. Test results comparison

No.	Load cell [kN]	Measurement plate [kN]	Error [%]
1	31.75	32.36	1.89
2	33.99	34.45	1.34
3	37.08	37.55	1.25
4	49.21	49.31	0.20

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