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Examination of Aircraft's Cable Control Systems Tension

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ABSTRACT
Cable control systems are widely used in GA aircrafts and gliders. The paper deals with the accuracy of measurement pertaining to the tension of cables at the production stage and the maintenance of aeronautical products. Producers of the measuring instruments used to measure tension do not explicitly define how they should be calibrated and stipulate using special methods and stands. The paper discusses a possible method of tension measurement, measuring tools, methods of calibration and possible errors in the adopted measurement and calibration methods as well. The possible error analysis takes into consideration, the stands construction and details: measuring the instruments system, temperature influence length of reference cable, etc.

Keywords: cable, tension measurement, tensiometer validation,

INTRODUCTION

Commonly used cable control systems in GA[1] aircraft, helicopters and gliders require periodical inspection, after a specific working time (flight hours) or a time interval, e.g. 1 year. During the inspection of cable systems of planes, the following are examined: cracks in wire of cable, friction wear of cables, fretting, corrosion, cable pulleys and skids abrasive wear, cable elongation, corrosion, cable socked, joint etc. Wear of cable and extension are nonlinear type of variation [5]. The required values of the cable tension of the cable control systems are determined in the design processes and calibrated by structural tests, airframe vibrations and flight tests. The subject of the article is the analysis of tension measurements of cable control systems based on the three-point bending method, by the strain gauge[2] [1]. The method is commonly used in determining the tension of ropes, cables, strings, and cable control systems of airplanes. Figure 1 demonstrates a typical cable control system of an airplane. The actual value of cable tension and their change during operation depends on the pilot/pilots effort, i.e. forces generated on the controls (CS.23.395 [3]) and the forces generated on the rudders surfaces are affected by the stiffness all elements of system control (cables – C1, fittings – C2), stiffness of the airframe structure (C3), and the actual temperature of the airframe units. Additionally, all aircraft operation requirements concerning control cable systems, pulleys, slides and forces must meet requirements[3], e.g. [3], including positive load forces in any flight or ground operating. All forces should be in the quasi linear range of stretching the cable Figure 2[4]. Loads of cable systems must additionally meet the requirements of cable manufacturers and other accepted or mandatory

[1] General Aviation, Certification Specification for Normal, Utility, Aerobatic and Commuter Aeroplanes and gliders in polish are named as light planes. In heavy aircraft (mass above 12 000 lbs), automatic tension adjustment systems are used.

[2] strain gauge – adopted in the Polish language, used in aviation, the name of a cable tension measurement tool borrowed from English (cable tensiometer)

[3] in analytical and certification practice, analytical and empirical evidence of compliance with legal requirements is required

[4] Designing the tension of cable airframe control systems is not the subject of this study.

requirements, including in the fatigue, diameters and construction of cable pulleys, arc of contact, required safety factors, etc.

The operating tensions of the aircraft control cables system are determined in the Aircraft Technical Service Manuals, with the influence of temperature assessment. The requirements are supported by the results of stiffness tests, real exploitation forces, vibration, and flight tests[5], including aeroelastic phenomena as well. Similar requirements are used in relation to cable systems with built-in autopilots. The loads control systems additionally includes the loads on the ground, e.g. loads from gusts and so-called brutal handling, parking etc. [3]. During operation, there is a change in the tension of cable systems caused by: the use of cables [4, 5] and fitting systems (pulleys, slides, covers, etc. [3, 6]) and their elongation and deflection. The changes in the tension of cable systems e.g. Figure 1, are caused by the variable movements and loads are a normal exploitation phenomenon[6].

The subject of the presented paper is a differential method adapted for determining the tension force of airframe control systems with strain gauges operating on the principle of three-point bending of a cable. Typical and service measurements are burdened with specific errors. Measurement of cable tension with a strain gauge is an indirect measurement method and based on measuring the transverse force related to the bending of a tensioned cable.

THE PRINCIPLE OF MEASUREMENT.

In practice of cable tension measuring with a strain gauge, there may be three cases given in Figure 3. (Drafts 1,2,3). Sketch 1, presents a case of cable tension measurement, with a determined reference cable length L, tensioned between rigid elements (deformation of the cable attachment are negligibly small) taking into account only the cable stiffness C1. Sketch 2 presents the case of measurement with one-sided fixing of the cable with its stiffness C1, loaded by a known force.

Sketch 3 shows the actual case of measurement of cable tension with a determined length L1, with rigidity of the system i.e.: C1 cable stiffness, C2 stiffness of control system (with fitting of the pulley and their deformation under actual load of system, fretting, wear and temperature) and C3 stiffness of the airframe (1). The actual stiffness and thermal changes affect the measurement results.

$$C_3 = \sum_{i=1}^{n} C_{3,i} \tag{1}$$

The paper analyzes the used method and details of measuring and errors with the influence of calibration results performed on reference cable lines on the final results of cable tension measurement. The presented results may be helpful in the preparation and implementation of structural tests, including the stiffness (susceptibility) examination of cable control systems, accepting or declining the possible spreads of measurement results, including measurement uncertainty and determination [3] – 23,619. The lateral deformations of the cable cased the axial force in the cable[7]. The angle of the cable between the base a of the measuring tool (Fig. 4) puts force on the support in the middle of the base and transfers the force to the spring of the strain gauge (C4) mechanically connected with the indicator system.

Used method and the construction of this type of instruments is characterized by errors defined by the formula (2) in accordance with Figure 4:

$$b \mp \Delta b = f\,(C\_4\,(\alpha \mp \Delta\alpha),\, C\_5\,(b + \Delta b)) \tag{2}$$

where: $+\,\Delta b$ – the error resulting from the dependence (dl, Rd), diameter and type of the cable and the radius of rounding the supports

$\pm\,\Delta\alpha$ – errors of the measuring system and gauge: systematic (hysteresis, indications, mechanical etc.) and random (wrong setting of the device in relation to the cable, wrong support beams, different instrument base)

The afore-mentioned parameters are not directly included in the presented results, but affect the accuracy of the measurement by the structure of the cable: material, the way of winding,

[5] CS 23.689, CS 23.397, CS 23.441, CS 23.455, CS 23.629, CS 23.683 and related AMC and FTG

[6] reduction of this effect is reduced by stretching the lines to a certain value of force prior to installation on the aircraft. Initial string tension in the subject literature is called "coaching" or preliminary tension, pre-tensioning and so-called cable training.

[7] In non-aircraft construction solutions, the use of ropes for carrying transverse loads, eg in horizontal rope transport, is used

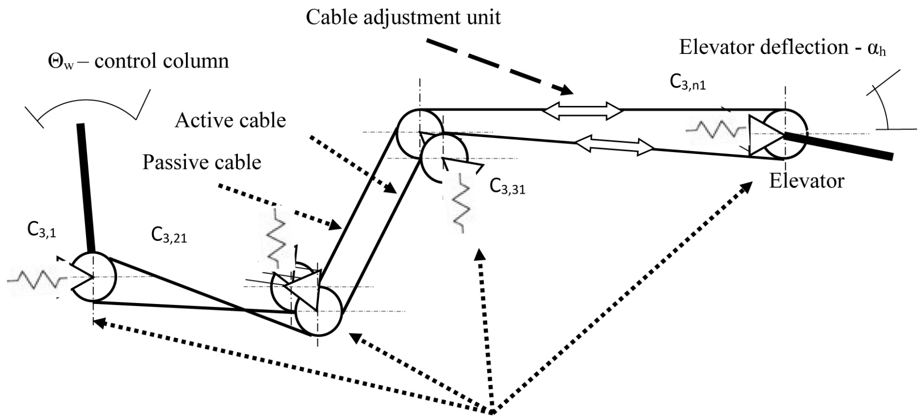

Fig. 1. Typical cable control system of elevator

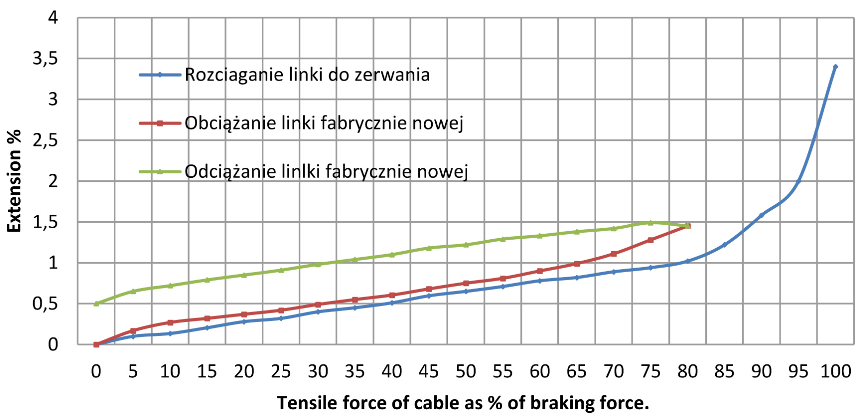

Fig. 2. Typical graphs of cable stretching

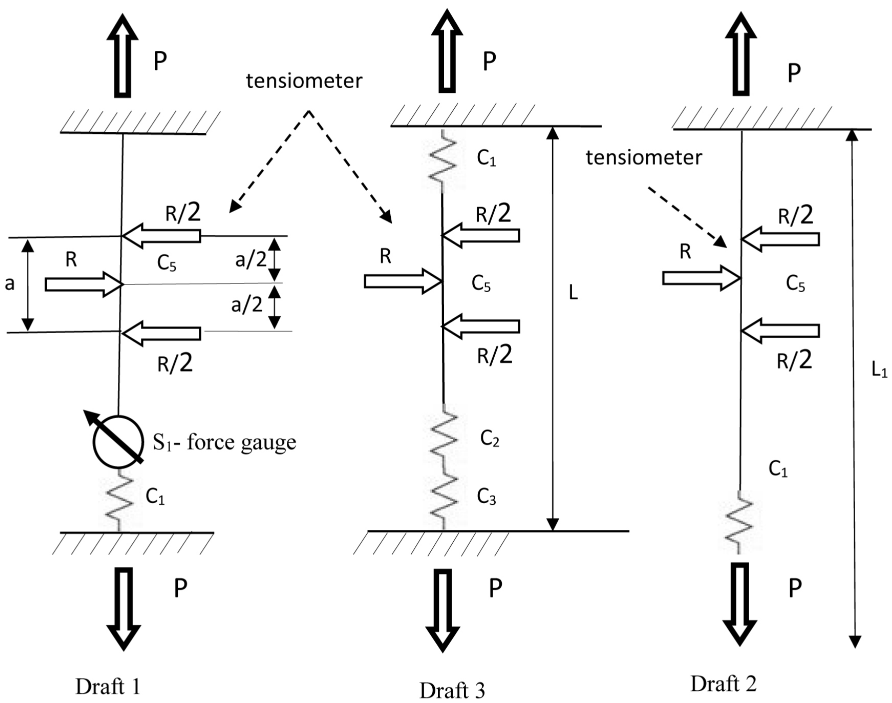

Fig. 3. Possible conditions for measuring the cable tension with a strain gauge

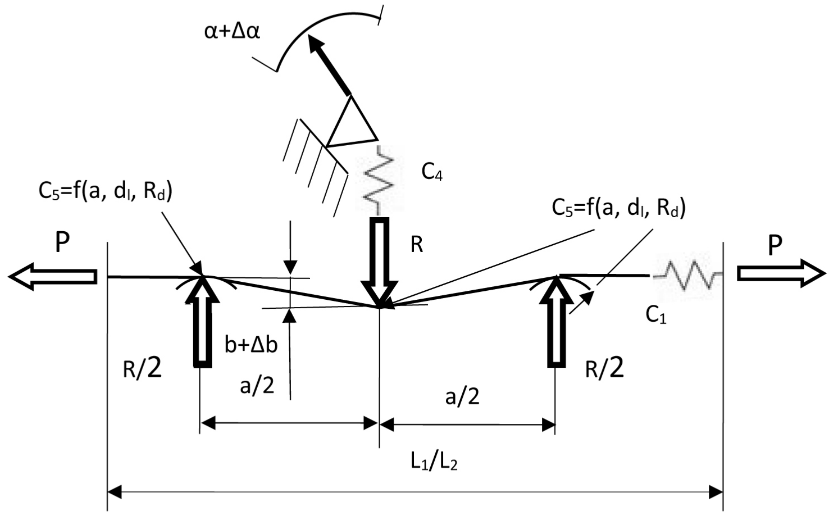

Fig. 4. Scheme of measurement of cable system tension with a strain gauge

diameters of wire etc. [6] All of them are included in the coefficient C5 defined in Figure 4.

EXAMINATION OF TENSIOMETERS

Examination of the device was carried out by performing measurements on a referred cable loaded by a known tensioned and then comparing with the measuring results and introducing corrections (systematic error). The devices can by examined on stands with two possible designs (Fig. 3.1 and Fig. 3.2). Both of them exist in practice and introduce errors. First of them is the effect of the lack of real conditions of calibration and measurement: airframe stiffness, rigidity of cable routing systems, cable length (Fig. 3.3). In the case given in Figure 3.2. the stiffness of the structure is omitted. The scheme of the stand presented in Figure 3.1 is convenient and universal for examination but is burdened with the greatest errors caused by the stiffness of fixing the reference cable and the strong influence of the cable length. Examination of the tensiometers on the stand described in Figure 3.1 is carried out with the following assumptions:

- the loads must be compatible with their permissible operating load and appropriate to the cable diameter and the measuring range of the examined strain gauge;
- device gauges S1 are used to calibrate the instruments (Fig. 3.1), with the current verification certificate (calibration);
- the strain gauge is prepared according to the diameter of the cable.

The stand described on Fig. 3.1 is a universal and the most commonly used, and the paper analyzes the errors for this case. In practice, the stand described in Figure 3.1, due to the overall dimensions indicated the cable is threaded through a set of cable pulleys (frictional forces are negligible), and the change in the value of the force is carried out by a screw or hydraulic system. Figure 5

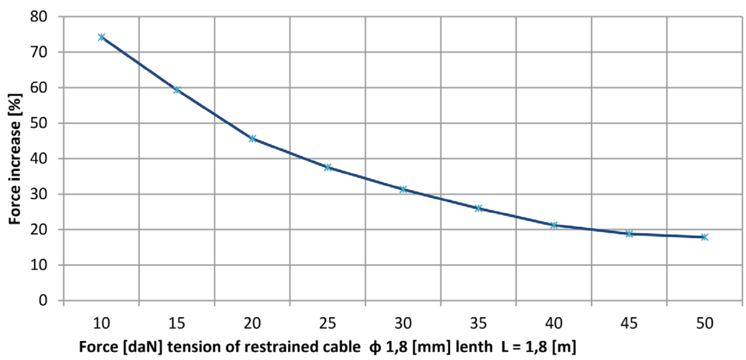

Fig. 5. Percentage increase in force due to strain gauge measurement as a function of cable tension force

shows the theoretical variation in tension (%) realized in accordance with the diagram 3.1 for a steel cable diam. φ 1.8 mm with a length of 1.8 m.

The observed effect of the loads apply by tensiometer on the cable tension value decreases with the increasing tension value of the examined cable Figure 5 and its length increase Figure 6 and Figure 7. as well. With a tension of approx. 5 daN, closing the device depending on the diameter of the cable causes a variation from 70% to 100%, and with a pre-tension of approx. 40 daN. This change is significantly reduced from 13% to 27%, for cable with approx. 280 daN breaking force.

The theoretical analysis of the influence the tensiometer fastening was carried out for cable with diam. of φ 1.8 mm and φ 4.5 mm, with different lengths based on [3], for the tensiometer with a base a = 85 mm. The calculation model [2,1] of the measuring by tensiometer consists of contact rigid elements and movable supports – according to Figure 4. The analysis omits the friction between the supports and the cable (the lines are lubricated) and the influence of the support beams depending on the tested cable diameter. The results of the calculations are presented in Figure 6 and Figure 7. They are related to a defined value of the tension of the system without control forces. The actual value of the cable tension in flight, Figure 1 is variable, according control surface and control deflection α_h and they are different in the active and reactive wire.

INFLUENCE OF THE BENDING DEFLECTION VALUE.

Theoretical analysis [2] of bending cable influence for the system as above for different cable lengths with diam. φ 1.8 and φ 4.5 are presented in Figure 8 and Figure 9.

THE INFLUENCE OF ENVIRONMENT TEMPERATURE

Aircrafts operate in the environment temperature range of +/- 60 ^{0}C and under these conditions they must meet all requirements [3]. The operational exploitation cable tension control systems variation with temperature influence on cable system (steel) for semimonocoque and monocoque planes constructions and steel cable diameters φ 3.2 mm up to φ 4.5 mm are approx. 35–60 daN. These values are approx. 2% of the breaking force of the cable

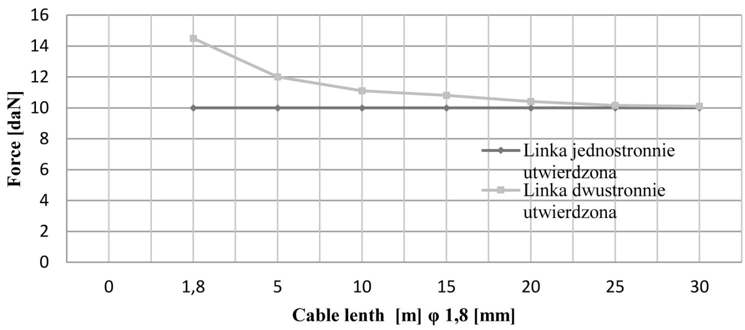

Fig. 6. The increase in force from the buttoned strain gauge as a function of the cable length φ 1.8 mm

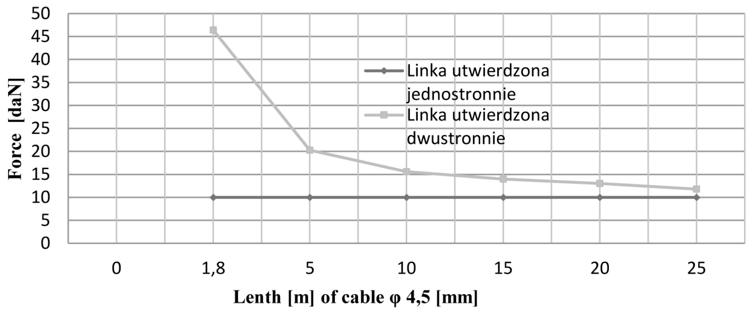

Fig. 7. Increasing the force in the cable φ 4.5 mm as a function of the length of cable.

and approx. 4–8% of the nominal operational forces. The theoretical determination of force variation in cable tension of plane cable control systems is limited due to the lack of information on the deflection of the control system (Fig.1 and Fig. 3.3) under actual loads. The details regarding the actual plane stiffness and the system's structure were obtained as the results of stiffness tests at operating loads for different temperatures. An example of such data is presented in Figure 10 prepared on the basis of the An-28 aircraft's Technical Service Manual.

Generally, the relationship of forces and temperature are linear or semilinear type. The nonlinearities relationships should appear more strongly in the cases of more built-up cable systems, e.g. pass by the passenger cabin, tanks, etc. For this reason, more reliable theoretical analyzes of the influence of temperature on the tension of the cable control systems will be in the case of simple structures. The numerical analysis [2] results of the simple cable control system for the diameter of the cable φ 3.5 mm are from 0.3077 daN/^{0}C to 0.5 daN /^{0}C. The available Technical Service Manuals of semi-closed and light aircraft, reports semilinear variable tension as function of temperature from 0.25 daN/^{0}C to 0.33 daN /^{0}C.

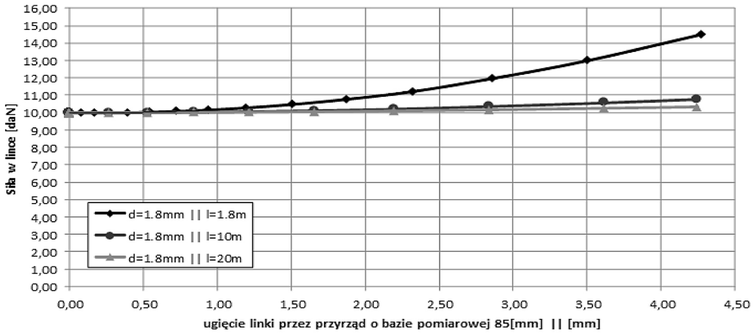

Fig. 8. Increasing the force in the cable φ 1.8 [mm] as a function of the deflection value of the device

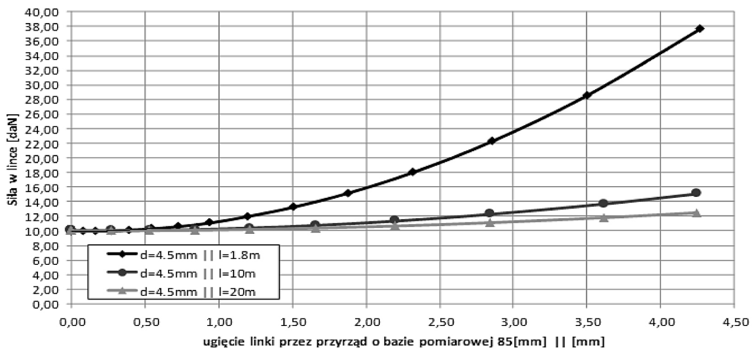

Fig. 9. Increasing the force in the rope φ 4,5 [mm] as a function of the deflection value of the device

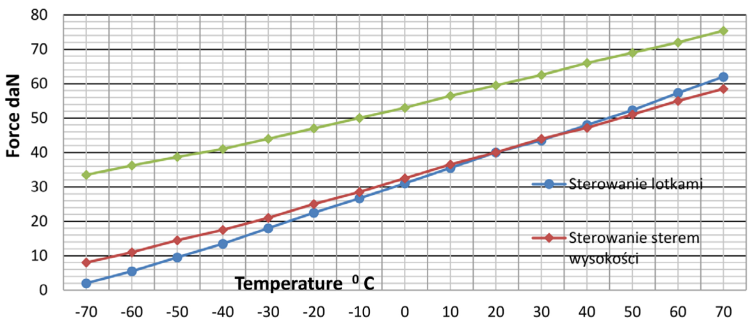

Fig. 10. The dependence the cable tension of the control systems depending on the temperature for An-28 aircraft

CONCLUSIONS

The results of analyses show that attractive and commonly used cable tension measurement of airplanes control systems and indicate the serious errors, up to a level that does not allow reliable measurement. The main errors of the used method are: the method of tensiometers examination should take into account the influence of cable length. The results show that in the instruments and cable systems serving as a standard for examining tensiometers (Fig. 3), their lengths should be comparable to real ones on an aircraft, i.e. around 12–20 m. On the basis of these requirements, we can obtain a final error of cable measurement approx. 5%. The influence of the cable diameter in practice is smaller because of Aviation Rules [3] that do not allow applying cable with the diameters smaller than φ 3.2 mm. The results of the analyses indicate that the tensiometers should be examined on different thicknesses of cables control system. The presented results of measurements using this method in the case of short cables (less than 10 m) should be verified in terms of the actual impact of the airframe structure stiffness in the load range concerned and development of corrections necessary to mark the tensiometer (Fig. 3.3). Similarly, verification should be conducted while assessing the influence of temperature on the stiffness of the control system. The presented results indicate that in the case of not taking into account the parameters mentioned above, the measurement errors may fluctuate at the level of technical acceptability, i.e. approx. 10%. An important aspect for aircraft designers and Aircraft Maintenance Instructions preparation is the necessity of clearly defining the conditions for examining extensiometers, i.e. determining the length of reference lines and their preparation, i.e. for example pre-tensioning (so-called cable training [6]) with specific values and defining the basis and value of forces used tensiometers. It seems appropriate to collect the stiffness structural and cable system data at the stage of structural tests, and further collect information on stiffness during flight tests at different ambient temperatures. This approach will reduce the measurement error to about 5–7%.

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