Comparative tests of bench equipment for fuel control system testing of gas-turbine engine

E V Shendaleva

Omsk State Technical University, 11, Mira av., Omsk, 644050, Russia

E-mail: shendalevaev@yandex.ru

Abstract: The relevance of interlaboratory comparative researches is confirmed by attention of world metrological community to this field of activity. Use of the interlaboratory comparative research methodology not only for single gages collation, but also for bench equipment complexes, such as modeling stands for fuel control system testing of gas-turbine engine, is offered. In this case a comparative measure of different bench equipment will be the control fuel pump. Ensuring traceability of measuring result received at test benches of various air enterprises, development and introduction of national standards to practice of bench tests and, eventually, improvement of quality and safety of a aircraft equipment is result of this approach.

1. Introduction
A quality and reliability of reference, calibrating, testing and measuring result in laboratories can be provided with laboratory participation in qualification test programs by means of interlaboratory comparison test during trueness and precision of characteristic measurement result of the same object will be defined in each laboratory [1].

Widespread introduction of interlaboratory comparative researches in modern practice was shown, first of all, in the field of substance and material characteristic measurements. But the methodology of comparative tests can be used also, for example, to other objects as gages established on places of their operation, or test benches. At the same time all compared and a control measuring instrument can be the identical level of accuracy [2].

2. Problem definition
We will consider tests of a fuel control pump (FCP) for fuel management systems (FMS) of gas-turbine engines (GTE). FCP tests and debugging are carried out at the semi-natural test bench [3, 4] containing the GTE imitating dynamic model [5], fuel-flow meter, electric drive and electropneumatic converter for providing FCP set characteristics (figure 1).

Measurements procedures are performed on the same object under identical circumstances don't yield, as a rule, identical results. Especially they differ if measurement conditions aren't identical. So results of tests of the same FCP at various stands often considerably differ from each other.

It is explained by existences of various factors which not always are giving in to control and inevitable casual errors inherent in each measuring procedure.

The test stand for FCP is much more difficult measuring tool, than single gages. Though for gages established at test benches, checking and calibration procedures are compulsory it doesn't solve a problem of test result traceability at different stands. Therefore it will be more correct when checking
bench equipment characteristics as a measure of checking to choose a fuel control pump, his entrance and output technical characteristics.

![Diagram](image_url)

**Figure 1.** The scheme of the semi-natural stand for FCP

I – GTE semi-natural model; II – FCP of fuel management system

CE and LE – control and locking elements, \( u_n, u_P \) – control signals for electric drive and electropneumatic converter, \( G_F \) – fuel consumption.

### 3. Theory

Tests which are carried out in the course of development, operational development and mass FCP production can be united in groups [6]:

1) research experiments at a stage of preparation for development of FCP;
2) tests of separate blocks which are carried out in the course of development and operational development of FCP;
3) smoothing and special tests of pilot FCP;
4) tests of serial FCP.

By mass production of FCP carry out bench tests:
- demand;
- acceptance;
- qualification;
- periodic;
- standard (technological).

In the course of mass production each FCP copy is subjected short-term (demand and acceptance) and to periodic tests. After the last the dismantling, survey, identification of detail defects and repeated assembly of FCP are made.

The FCP debugging is corrected by the result of demand tests, and then cycles of FCP check and bench development is repeated on the FCP collaboration modes with the GTE semi-natural model. A final inspection and adjustment of the fuel control pump are carried out during acceptance tests.

FCP qualification tests are carried out after passed acceptance tests, for the purpose of held action assessments of earlier revealed shortcoming elimination and production transfer to the customer.

Periodic tests are carried out for monitoring of production and technological processes stability. The resource equivalent cyclic test providing the set quantity of start, acceleration and discharge cycles and also the set operating time on maximum modes according to established requirements to resource of the fuel control pump often act as periodic tests.

Thus, all life cycle of FCP is accompanied by different types of tests. At the same time use of «reference» FCP as a comparison measure for other fuel control pumps and identification of FCP with...
unsatisfactory characteristics doesn't allow speak with high degree of confidence about reliability of the received result.

Test stands for FCP represent a difficult constructions equipped with power equipment, equipment of a fuel feed system and air-gas communications, control systems, monitoring and measurements. The fuel equipment tests are accompanied by expenses of the electric power, fuel and other resources for which decrease it is necessary to increase informational content of tests and accuracy of measurement results.

In modern FMS GTE management programs are realized:

\[ n_{LP} = f(\alpha_{ECL}, T^*_{IN}, P^*_{IN}), \quad n_{HP} = f(\alpha_{ECL}, T^*_{IN}, P^*_{IN}), \quad \pi_{CS} = f(\alpha_{ECL}), \quad \pi_{GTE}^* = f(\alpha_{ECL}, T^*_{IN}, P^*_{IN}, M_N), \]

where \( n_{LP} \) – the rotor rotation frequency of low pressure compressor (LPC);
\( \alpha_{ECL} \) – air stagnation temperature on an entrance to the engine;
\( T^*_{IN} \) – air pressure behind the compressor;
\( P^*_{IN} \) – extent of increase in the engine air pressure;
\( P^*_{C} \) – air pressure behind the compressor;
\( P^*_{T} \) – gas pressure behind the turbine;
\( M_N \) – Mach number.

The management of an operating mode in the reserve fuel control pump can be carried out on simplified programs:

\[ n_E = f(\alpha_{ECL}), \quad n_{HP} = f(\alpha_{ECL}), \quad G_F = f(\alpha_{ECL}), \quad G_F / P^*_{C} = f(\alpha_{ECL}), \]

where \( n_E \) – the rotor rotation frequency of the exhauster;
\( G_F \) – fuel consumption in the main combustion chamber.

Dynamic characteristics of fuel control pumps are defined on transitional modes: acceleration, dumping, partial acceleration and dumping, advanced acceleration.

Management of fuel consumption is carried out according to programs:

\[ \dot{n}_{HP} = f(n_{HPs}, P^*_{IN}), \quad \dot{n}_{LP} = f(n_{HPs}, P^*_{IN}), \quad G_F / P^*_{C} = f(n_{HP}), \quad G_F / P^*_{T} = f(n_{LP}), \]

where \( n_{HPs} \) – the specified rotation frequency of HPC rotor.

Reserve programs of management have an appearance:

\[ n_{HP} = f(\tau), \quad G_F = f(\tau), \quad G_F = f(\pi^*_{C}), \quad G_F = f(P^*_{C}), \quad G_F = f(\tau, P^*_{C}), \quad G_F = f(P^*_{C}, P^*_{IN}), \]

where \( \tau \) – time.

At acceleration mode management programs of fuel consumption are applied as in intra motive parameters ( \( P^*_{C}, T^*_{C}, n_{HP} \) or their combinations), and start on time. Management programs for intra motive parameters have an appearance:

\[ G_F / P^*_{C} = \text{const}, \quad G_F / P^*_{C} = f(n_{HPs}), \quad G_F / P^*_{C} = f(n_{HPs}, T^*_{C}), \quad G_F / P^*_{C} = f(n_{HPs}), \]

where \( T^*_{C} \) – gas temperature behind the compressor;
\( GFs \) – reduced fuel consumption in the main combustion chamber.

Management programs of fuel consumption for time has an appearance

\[ G_F = f(\tau), \quad dG_F / d\tau = \text{const}, \quad dG_F / d\tau = f(n_{HP}), \quad n_{HP} = f(\tau). \]

As directly set or prototype parameters at FCP of the GTE frequency rotation regulation contour tests consider:
– the rotor rotation frequency of the exhauster or LPC;
– the rotor rotation frequency of HPC;
– air pressure behind the compressor;
– extent of increase in compressor air pressure.

The FCP output parameter is fuel consumption $G_F$

Due to the need of various factor influences for correct understanding at compared test benches the same FCP has to be tested. As the purpose of comparative tests in this case will be «test» of test benches, but not the FCP, his design has no essential value. It is necessary to test, at least, two fuel control pumps of the same type on each of compared stands for more clear interpretation of the stand and FCP influence into repeatability and reproducibility of bench test results [7].

At a choice of comparison base for FCP output characteristics at different stands it is necessary to prefer complex characteristics, such as $G_T/n_{HP}$, $G_T/P'_C$, $\pi_{CZ}$, that is connected with high sensitivity of complex characteristics to parameter changes.

Among all bench measurement instrumentation flow meter indications [8] have the most considerable dispersion especially as flow meters of various dimension-types can be used at various measurement levels. Therefore along with the chosen measures of stand checking (FCP) it is necessary to use additional checking measures of fuel consumption gages [2], for example, reference mass flow meters.

FCP tests are carried out in reproducibility conditions under which test results receive by the same method, on one device under test, but at different stands, different operators, with various equipment using.

Under one FCP test the measured parameter dispersion [9] at the stand $i$

$$s^2_{ij} = \left( n_{ij} - 1 \right)^{-1} \sum_{k=1}^{n_{ij}} (\bar{y}_{ij} - y_{ijk})^2,$$

(1)

where $k$ – the single measurement index on $j$-level of $i$-stand;
$j$ – measurement level (ECL);
$n_{ij}$ – the number of measurements on $j$-level of $i$-stand;
$\bar{y}_{ij}$ – average value of measurement results on $j$-level of $i$-stand

$$\bar{y}_{ij} = n_{ij}^{-1} \sum_{k=1}^{n_{ij}} y_{ijk}.$$

(2)

Repeatability dispersion of the measured parameter

$$s^2_{rj} = \frac{\sum_{i=1}^{p} (n_{ij} - 1) s^2_{ij}}{\sum_{i=1}^{p} (n_{ij} - 1)},$$

(3)

where $p$ – number of stands.

Interbench (interlaboratory) dispersion of test results

$$s^2_{lj} = \frac{s^2_{dj} - s^2_{rj}}{\bar{n}_j},$$

(4)

where

$$s^2_{dj} = \frac{1}{p-1} \sum_{i=1}^{p} n_{ij} \left( \bar{y}_{ij} - \bar{y}_j \right)^2;$$

(5)

$\bar{n}_j$ – medium of measurements on $j$-level of all stands

$$\bar{n}_j = \frac{1}{p-1} \left[ \sum_{i=1}^{p} n_{ij} - \left( \sum_{i=1}^{p} n_{ij} \right) \cdot \left( \sum_{i=1}^{p} n_{ij} \right)^{-1} \right];$$

(6)
$\bar{y}_j$ – average value of measurement results on $j$-level of all stands

$$\bar{y}_j = \left( \sum_{i=1}^{p} n_{ij} \bar{y}_{ij} \right) \cdot \left( \sum_{i=1}^{p} n_{ij} \right)^{-1}. \quad (7)$$

Reproducibility dispersion of the measured parameter

$$s_{ij}^2 = s_{ij}^2 + s_{ij}^2. \quad (8)$$

In the presence of accepted reference value $\mu_{ij}$ for measured parameter (specifications, passport) the critical difference of reference value and average of parameter on each of stands [10]

$$CD_{ij} = \frac{2.8}{\sqrt{2}} \sqrt{s_{ij}^2 - s_{ij}^2 \left( 1 - \frac{1}{n_{ij}} \right)}. \quad (9)$$

Critical difference of reference value and general average of parameter for several stands

$$CD_j = \frac{2.8}{\sqrt{2p}} \sqrt{s_{ij}^2 - s_{ij}^2 \left( 1 - \frac{1}{p} \sum_{i=1}^{p} \frac{1}{n_{ij}} \right)}. \quad (10)$$

In the presence of two FCP it is possible to consider not only the accuracy of bench control and measurement systems, but also the errors brought by FCP [7].

For this purpose define:

a) arithmetic mean of test results and a divergence between test results ($k = 1, 2$) for each FCP on $j$-level of $i$-stand

$$\bar{y}_{ij} = \left( y_{ij1} + y_{ij2} \right)/2, \quad (11)$$

$$w_{ij} = \left| y_{ij1} - y_{ij2} \right|; \quad (12)$$

b) arithmetic mean of test results and a divergence between average values of test results ($t = 1, 2$) for both FCP on $j$-level of $i$-stand

$$\bar{y}_{ij} = \left( \bar{y}_{ij1} + \bar{y}_{ij2} \right)/2, \quad (13)$$

$$w_{ij} = \left| \bar{y}_{ij1} - \bar{y}_{ij2} \right|; \quad (14)$$

c) arithmetic mean of parameter and a standard deviation for both FCP on $j$-level of both stands

$$y_j = p^{-1} \sum_{i=1}^{p} \bar{y}_{ij}, \quad (15)$$

$$s_{ij} = (p-1)^{-1/2} \cdot \left[ \sum_{i=1}^{p} \left( \bar{y}_{ij} - \bar{y}_j \right) \right]^{1/2}. \quad (16)$$

d) divergence squares sum between test results for each FCP on $j$-level of $i$-stand ($t=1, g; i=1, p$)

$$SS_{ij} = \sum_{i=1}^{p} \sum_{g=1}^{g} w_{ij}^2; \quad (17)$$

e) divergence squares sum between arithmetic means of test results for both FCP on $j$-level of $i$-stand ($i=1, p$)

$$SS_{ij} = \sum_{i=1}^{p} w_{ij}^2; \quad (18)$$

f) dispersions of repeatability and reproducibility

$$s_{ij}^2 = \frac{SS_{ij}}{4p}, \quad (19)$$
g) dispersions which are divergence measures between parameter values of different FCP

\[ s^2_{ij} = s^2_{ij} + \frac{SS_{ij} - SS_{ij}}{4p}; \] (20)

During FCP tests at the modeling test bench the data on fuel consumption, rotor rotation frequency of the high pressure compressor (electric drive) and pressure behind the compressor (electric-pneumatic converter) provided in table 1 have been obtained.

4. Discussion of results of an experiment

The calculation executed for one FCP according to (1) – (10) (table 2) show that conditions on a critical difference

\[ CD_g > |\mu_{o_j} - \bar{y}_j| \]

and

\[ CD_j > |\mu_{o_j} - \bar{y}_j| \]

are executed not completely. As final results of tests it is possible to use average values of the FCP parameters on two stands except for fuel consumption for both stands at = 45 angular degree and rotation frequency for the first stand at = 83 angular degree.

Non-performance of conditions on a critical difference at FCP tests speaks about considerable influence of stand variability factors. For a research and elimination of this influence it is necessary to use multifactorial experiments.

Results of calculation for two FCP (11) – (21) (table 3) show that a standard deviation \( s_H \) for fuel consumption \( G_F \) at = 45 angular degree exceeds a reproducibility standard deviation \( s_R \). It means that distinction influence of two FCP on test accuracy is higher than influence of other stand factors.

Besides FCP distinction influence on the rotation frequency \( n_{HP} \) is comparable to influence of other factors operating at the stand.

5. Abstract and conclusions

Carrying out inter-bench comparative tests with one or several FCP as samples for comparison allows impartial estimating both trueness and precision of test benches, and statistical uniformity of FCP parameter values. Standardization of FCP comparative tests and adaptation of corresponding statistical methods for measurement results processing of various parameters will provide reasonable values of characteristics for fuel control pumps and test benches.

6. References:

[1] GOST R ISO 5275-1-2002 Russia Accuracy (correctness and precision) of measurement methods and results. Part 1. Basic provisions and definitions Moscow: Publ. house of standards

[2] MI 1832–88 Russia State system of measurement ensuring unity. Group verification of checking means for identical accuracy level. Basic rules: Methodical instructions Moscow: Publ. house of standards

[3] Shendaleva E V, Zhiltsov V V and Tetter V Y 2005 Russia The fuel apparatus adjustment technology for automatic control systems of gas turbine engines with model stands using. Assembling in mechanical engineering and instrument making 7 p 15-21

[4] Shendaleva E V 2017 Russia The regulation of gas turbine engine automatic control system in time of trials for technologic state forecasting SibADI bulletin 3 (55) p 111 – 19

[5] Shendaleva E V 2012 Russia Gas turbine engine simulation in state space: dynamic aspect. SibADI bulletin 5 (27) p 101 – 06

[6] Aleksandrovskaia L N, Kruglov V I, Kuznetsov A G, Kuznetsov V A and Kutin A A and Sholom A M 2003 Testing theory and experimental processing of complex technical systems Moscow: Logos p 735

[7] GOST R ISO 5275-5-2002 Russia Accuracy (correctness and precision) of measurement methods and result. Part 5. Alternative methods of precision definition for standard measurement method Moscow: Publ. house of standards
[8] German V M, Avgustovich V G, Arkhipov G N, Bereznjakov S V, Pipekin V I, Rakitin M M, Ryzhov I D, Sakhatdinov V N and Smolko V V and Tchervanjuk V V 1990 Optimization methods for tests and simulation of control systems for gas turbine engines ed Vasilchenlo K J, Dolgolenko G P, Znamenskaja A M, Kljachko V D, Mahonkin Y E, Mironov A D, Hejftets M I under the editorship of . Dedesh V T (Moscow: Mechanical engineering p 160)

[9] GOST R ISO 5275-2-2002 Russia Accuracy (correctness and precision) of measurement methods and results. Part 2. Main repeatability and reproducibility procedure for standard measurement method Moscow: Publ. house of standards

[10] GOST R ISO 5275-6-2002 Russia Accuracy (correctness and precision) of measurement methods and results. Part 6. Use of accuracy values in practice Moscow: Publ. house of standards
| Technical characteristics | $\alpha_{\text{ECL}}, \text{angular degree}$ | Stand 1 | Stand 2 | Parameter values on specification |
|---------------------------|----------------------------------------|---------|---------|-------------------------------|
| Fuel control pump 1       |                                        |         |         |                               |
| Fuel consumption $G_F$, kg/h | 45                                     | 1426    | 1428    | 1429 | 1431 | 1420 |
|                           | 83                                     | 2973    | 2981    | 2983 | 2979 | 3000 |
|                           | 120                                    | 3396    | 3387    | 3378 | 3388 | 3400 |
| Air pressure behind the compressor $P_C^*$, kg/cm$^2$ | 45                                     | 4.63    | 4.68    | 4.71 | 4.76 | 4.7  |
|                           | 83                                     | 8.87    | 8.96    | 9.05 | 8.99 | 9.0  |
|                           | 120                                    | 11.92   | 12.03   | 11.96 | 11.91 | 12.0 |
| Rotor rotation frequency of high pressure compressor $n_{HP}$, min$^{-1}$ | 45                                     | 4141    | 4139    | 4122 | 4132 | 4130 |
|                           | 83                                     | 4762    | 4753    | 4752 | 4753 | 4750 |
|                           | 120                                    | 4881    | 4896    | 4894 | 4895 | 4890 |
| Fuel control pump 2       |                                        |         |         |                               |
| Fuel consumption $G_F$, kg/h | 45                                     | 1429    | 1427    | 1419 | 1421 |
|                           | 83                                     | 3012    | 3011    | 3006 | 3008 |
|                           | 120                                    | 3398    | 3407    | 3405 | 3409 |
| Air pressure behind the compressor $P_C^*$, kg/cm$^2$ | 45                                     | 4.71    | 4.73    | 4.72 | 4.79 |
|                           | 83                                     | 9.07    | 9.06    | 8.95 | 9.04 |
|                           | 120                                    | 12.18   | 12.12   | 12.13 | 12.07 |
| Rotor rotation frequency of high pressure compressor $n_{HP}$, min$^{-1}$ | 45                                     | 4131    | 4134    | 4127 | 4129 |
|                           | 83                                     | 4753    | 4755    | 4747 | 4745 |
|                           | 120                                    | 4895    | 4886    | 4893 | 4896 |

Table 1. Data of experiments.

| Characteristic | $\alpha_{\text{ECL}}$, Stand | $\bar{y}_{ij}$ | $\bar{y}_j$ | $\mu_y$ | $s^2_{ij}$ | $s^2_{ij}$ | $\mu_0 - \bar{y}_j$ | $CD_{ij}$ | $|\mu_0 - \bar{y}_j|$ | $CD_{ij}$ |
|----------------|-------------------------------|----------------|------------|---------|------------|------------|-------------------|--------|----------------------|--------|
| $G_F$, kg/h    | 45                            | 1427           | 1428       | 1420    | 2.00       | 2.00       | 7.00              | 1.98   | 7.50                  | 1.40   |
|                | 2                             | 1428           | 1428       | 2.00    | 2.00       | 8.00       | 1.98              |        |                      |        |
|                | 83                            | 2977           | 2994       | 3000    | 32.00      | 0.50       | 23.00             | 48.47  | 5.75                  | 34.27  |
|                | 2                             | 3012           | 3000       | 0.50    | 16.25      | 607.31     | 11.50             | 48.47  |                      |        |
|                | 120                           | 3392           | 3397       | 3400    | 40.50      | 40.50      | 8.50              | 16.64  | 3.00                  | 11.77  |
|                | 2                             | 3403           | 3403       | 40.50   | 90.88      | 40.50      | 2.50              | 16.64  |                      |        |
| $P_C^*$, kg/cm$^2$ | 45                            | 4.66           | 4.69       | 4.70    | 0.0012     | 0.0007     | 0.0045            | 0.095  | 0.013                 | 0.067  |
|                | 2                             | 4.72           | 4.69       | 4.70    | 0.0002     | 0.0002     | 0.020             | 0.095  |                      |        |
|                | 83                            | 8.92           | 8.99       | 9.00    | 0.0041     | 0.0000     | 0.0085            | 0.215  | 0.010                 | 0.152  |
|                | 2                             | 9.07           | 8.99       | 9.00    | 0.0021     | 0.01       | 0.065             | 0.215  |                      |        |
|                | 120                           | 11.98          | 12.06      | 12.00   | 0.0060     | 0.0018     | 0.025             | 0.253  | 0.063                 | 0.179  |
|                | 2                             | 12.15          | 12.06      | 12.00   | 0.0039     | 0.02       | 0.150             | 0.253  |                      |        |
| $n_{HP}$, min$^{-1}$ | 45                            | 1410           | 4136       | 4130    | 2.00       | 3.25       | 10.00             | 10.65  | 6.25                  | 7.53   |
|                | 2                             | 4133           | 4136       | 4130    | 4.50       | 30.56      | 2.50              | 10.65  |                      |        |
|                | 83                            | 4758           | 4756       | 4750    | 40.50      | 21.25      | 7.50              | 6.70   | 5.75                  | 4.73   |
|                | 2                             | 4754           | 4756       | 4750    | 2.00       | 22.06      | 4.00              | 6.70   |                      |        |
|                | 120                           | 4889           | 4890       | 4890    | 112.50     | 76.50      | 1.50              | 12.25  | 0.50                  | 8.66   |
|                | 2                             | 4891           | 4890       | 4890    | 40.50      | 76.50      | 0.50              | 12.25  |                      |        |
Table 3. Computational results for two fuel control pumps.

| Characteristics | $\alpha_{ECL}$ | Stand | FCP | Test | $\bar{y}_{ij}$ | $w_{ij}$ | $\bar{y}_{j}$ | $w_{ij}$ | $\bar{SS}_S$ | $SS_{Hj}$ | $s_{Rj}$ | $s_{Hj}$ |
|-----------------|---------------|-------|-----|------|----------------|--------|-------------|--------|-------------|----------|---------|---------|
| $G_F$, kg/h     | 45            | 1     | 2   | 1    | 1426          | 4124   | 1427        | 2      | 1428.5      | 4.5      | 1426    | 16.0    | 73.0    | 1.78    | 4.15    |
|                 |               | 2     | 1   | 1    | 1429          | 1431   | 1430        | 4      | 1424.0      | 30.3     | 2994    | 85.0    | 36.3    | 21.53   | 1.94    |
|                 |               | 2     | 2   | 1    | 1419          | 1421   | 1420        | 2      | 2979.0      | 3396     | 3387    | 3392    | 9       | 3387.3  | 17.5    | 3396    | 278.0   | 92.5    | 13.28   | 2.4     |
| $P_C^*$, kg/cm² | 45            | 1     | 1   | 1    | 4.63          | 4.68   | 4.66        | 0.05   | 0.043       | 4.72     | 0.001   | 0.008   | 0.035   | 0.001   | 4.70    |
|                 |               | 2     | 1   | 1    | 4.71          | 4.76   | 4.74        | 0.05   | 0.003       | 4.72     | 0.001   | 0.008   | 0.035   | 0.001   | 4.74    |
|                 |               | 2     | 2   | 1    | 8.87          | 8.96   | 8.92        | 0.09   | 0.063       | 9.00     | 0.003   | 0.016   | 0.050   | 0.003   | 9.03    |
|                 |               | 2     | 2   | 2    | 9.05          | 9.09   | 9.10        | 0.11   | 11.92       | 12.03    | 11.98   | 11.94   | 0.05    | 11.96   | 12.13   |
| $n_{HP}$, min⁻¹ | 45            | 1     | 1   | 1    | 4141          | 4139   | 4140        | 2      | 12.13       | 4132     | 117.0   | 189.3   | 11.35   | 1.52    | 3.2     | 4130.3  |
|                 |               | 2     | 1   | 1    | 4122          | 4132   | 4127        | 3      | 4133.5      | 4132     | 117.0   | 189.3   | 11.35   | 1.52    | 3.2     |
|                 |               | 2     | 2   | 1    | 4131          | 4134   | 4133        | 3      | 4130.3      | 4132     | 117.0   | 189.3   | 11.35   | 1.52    | 3.2     |
|                 |               | 2     | 2   | 2    | 4127          | 4129   | 4128        | 2      | 4133.5      | 4132     | 117.0   | 189.3   | 11.35   | 1.52    | 3.2     |

**Information about the author:**

Elena V. Shendaleva (Omsk, Russian Federation) – Ph. D. in Technical Sciences, Ass. Professor, Department of Oil & Gas Business, Standardization and Metrology, Omsk State Technical University (644050, Mira prospect, 11, Omsk, Russian Federation, e-mail: shendalevaev@yandex.ru)

E. V. Shendaleva

Omsk State Technical University, Russian Federation, Omsk
Keywords: comparative tests, fuel control system equipment, gas-turbine engine, test bench.