Equipment for Quality Assessment of the Copper Pipes and Fittings Used within Natural Gas Installations

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Abstract: The present paper describes the equipment conceived, designed and built by the authors, during a complex research program, in order to perform the tests required for the quality assessment of the permanent assembly technologies used within the natural gas installations made of copper pipes. The research work addressed below is part of our effort (detailed in a separate paper [1]) aiming at making possible the use, within the natural gas installations in Romania (alongside steel and polyethylene pipes), of copper pipes assembled using the press fit technology, by aligning the Romanian standards to the European ones. The equipment described in the paper can be used to investigate the dynamic strength under torsion loads, the dynamic strength under bending loads (vibrations) and the operating capacity at high temperature of the joints and fittings for copper pipes.

Keywords: natural gas installations; copper pipes; fittings; press fit; hard soldered joints; quality assessment.

1. Introduction

Currently, a generalisation of the use of copper as a material for the construction of natural gas internal installations can be noticed world-wide. Moreover, the use of a new procedure for the permanent assembly of copper pipes and fittings for such installations (i.e. press fit jointing / cold pressing / crimping, using a special metallic or non-metallic sealing element) has been proposed as an alternative to the traditional procedures (brazing or welding). These issues have been detailed by the authors in a separate paper [1], in which the advantages of using copper pipes and these assembly technologies have also been commented.

In such framework, the research work results presented in this paper aimed at conceiving, designing and building the equipment required to assess/certify the quality of the assembly technology (with press fit or hard soldered joints) of the copper pipes used within the natural gas installations. The designed equipment has been conceived on purpose to follow the testing procedures, presented in [1-3], defined by the authors based on the European norms addressing the use of copper pipes for gas installations [4-11].

The following equipment developed to test copper pipes assemblies is described in the present paper: equipment for the strength and tightness testing under dynamic torsion loads; equipment used to test the dynamic strength under bending loads (vibrations); equipment used to test the operating capacity at high temperatures.

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2. Equipment for the Dynamic Strength Testing under Torsion Loads of Copper Pipes Joints

The equipment (shown in the scheme from Figure 1 and the picture from Figure 2) designed to investigate the dynamic strength under torsion loads of the joints resulted from pressing or hard soldering of the copper pipes has been conceived – according to the testing procedure developed by the authors and described in [1-3] – to subject a full-scale test specimen made up of a fitting, 8, and two copper pipes, 5 and 7, to a symmetrical alternating torsional stress, at room temperature and atmospheric pressure. One end of the specimen, 5, is rigidly fixed, and the other end, 7, is subjected to an alternating rotation at a constant specified amplitude (± 5°) with a specified frequency, defined by a specified number of load cycles (10), each one with a specified duration (one second). The equipment is made up of an electrical motor, 2, provided with an actuator mechanism which performs an alternating rotation of the end 7 of the specimen, while the other end 5 is firmly fixed by means of a holding device 4.

The main elements of the equipment designed by the authors, are briefly described below and can be seen in Fig. 1 and Fig. 2:

- a frame, 1, on which all the other components are fixed;

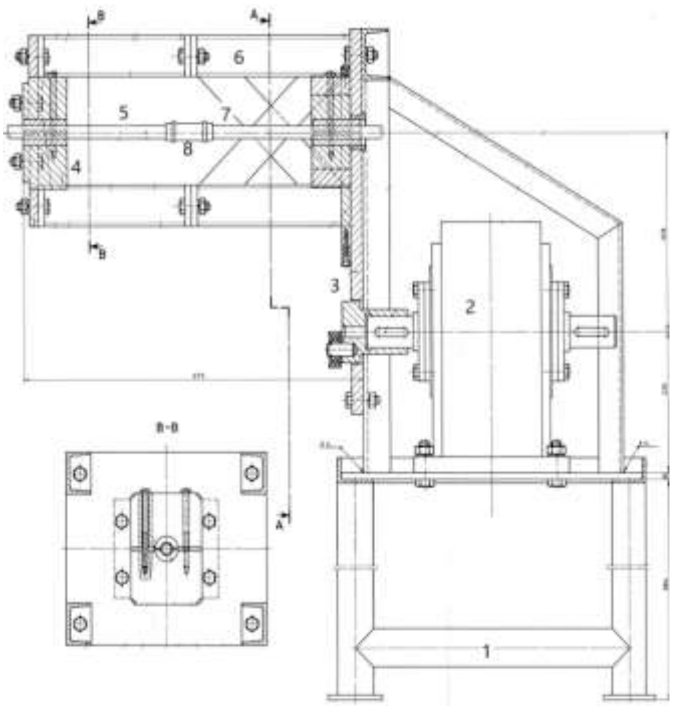

Fig. 1. Scheme of the equipment for the strength test under symmetrical alternating torsion loads of copper pipes joints:
1 – frame; 2 – electrical motor; 3 – motion transmission device; 4 - pipe retaining device;
5 – pipe fixed (left) end; 6 – sustaining elements; 7 – pipe right end; 8 – fitting

a)

b)

Fig. 2. Pictures of the equipment for the strength test under symmetrical alternating torsion loads of copper pipes joints:
a) front view; b) upper view:

- an electrical actuator mechanism, 2, to which a motion transmission device, 3, is connected;
- a retaining device, 4, made up of two fishing sockets fixed on a guide plate, which rigidly sustains the left end, 5, of the tested specimen;
- sustaining elements, 6, made of welded assemblies, for the retaining device, 4, and the motion transmission device, 3; the main element is a foot plate (fixed to the frame 1 by means of a support), directly sustaining the devices 3 and 4;

- the device 3, which transmits the motion from the driving shaft of the actuator mechanism, 2, to the right end, 7, of the specimen, is made of the following main elements:
  - the leading element, a bushing fitted on the driving shaft of 2, with an eccentric catch pin provided with a bearing (the first kinematic coupling of the mechanism),
  - a fishing plate transmitting the motion from the bushing to the driving pin,
  - a driving pin (provided with an eccentric catch pin with a bearing – the second kinematic coupling of the mechanism), transmitting the motion to the retaining device of the end 7 of the specimen,
  - the retaining device for the end 7 of the specimen, made up of a guide plate, two blades and two fishing sockets (with the role of a friction kinematic coupling, together with a bushing guide fitted on a bed plate).

As driving mechanism for the conceived equipment, an electrical driving system has been selected in its most convenient version (from both the economic and the reliability points of view) of a three-phased induction motor.

The equipment functions as follows: the end 7 of the specimen is subjected to an alternative rotational motion by the means of the driving mechanism 3, while the end 5 remains fixed. The amplitude of the motion is determined by the dimensions of the elements of the driving mechanism and it corresponds to the one defined within the elaborated testing procedure (± 5°).

The design process of the equipment for the dynamic strength testing under torsion loads, detailed in [2], has taken into account the following main issues:

- the adoption of the simplest and most reliable possible kinematic scheme (a driving mechanism with the minimum number of kinematic elements);
- the conception of an equipment with the smallest dimensions possible and very easy to handle, especially from the point of view of the simplest way to assemble the specimen;
- the design of the retaining devices of the specimen in order to avoid the event of a break or a slit in this area; to such purpose, the length of the fishing sockets and of the holding blades has been determined by assessing the contact pressure exercised on the copper pipes of the specimen, so that their surface should not be damaged;
- the assurance of a high rigidity of the equipment; as a result, among other things, the holding blades of the end 5 of the specimen have been oversized;
- the selection of the materials from which the components of the equipment were made in order to obtain the necessary mechanical strength properties at the lowest price; the stress to which these elements are submitted having relatively low values, plain carbon steel has been selected.

After conceiving a first scheme, the main elements of the equipment have been designed taking into account the typical formula for simple stress and considering the main forces that act upon them, that is those that result from the weight of the sustained elements and those developed from the driving mechanism (assessed on the basis of the kinematic and dynamic analysis briefly presented below).

The result of the test is considered to be positive and the tested type of assembly is considered to be compliant if, after the test, the specimen keeps its tightness. To this purpose, the specimen is finally submitted to a tightness test under internal pneumatic pressure, at room temperature (using the set up shown in Fig. 3), following the procedure 2 as described in [1].

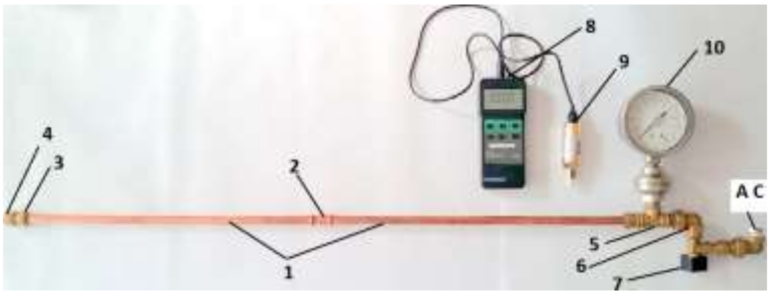

Fig. 3. Tightness testing of the specimen at internal pneumatic pressure:
1 – copper pipes, 2 – fitting, 3 – Geko part, 4 – cap, 5 – tee, 6 – elbow, 7 – valve,
8 – pressure gauge (≤ 2 bar), 9 – pressure transducer, 10 – manometer (< 10 bar);
AC – compressed air.

The driving mechanism designed for the equipment has been analysed by assimilating it to a quadrangular mechanism, according to the kinematic scheme included in Fig. 4. The three kinematic elements of the model considered for the mechanism, are the following:

- The conducting element, *AB*, with the adopted length l_1 = 30 mm, corresponding to the eccentric device, fitted to the driving shaft of the electrical motor, made up practically of the bushing with eccentric catch pin. The angular speed of this element, ω_1, is constant; according to the testing procedure (which requires a stress cycle duration of one second), it shall have the value: ω_1 = 6.0 rad/s.
- The driven element, *BC*, which corresponds to the fishing plate and has the adopted length l_2 = 110 mm (defined on the basis of a kinematic analysis of several possible values).
- The balancing element, *CD*, which must perform a rotational swinging motion with the amplitude defined in the testing procedure (± 5°), is made up of the driving pin with eccentric catch pin and the fixing device of the mobile end of the specimen. Its length was adopted (based on a kinematic analysis) at the value l_3 = 327 mm.

The motion transmission mechanism has the following kinematic rotating couplings (see Fig. 4): *A*, between the conducting element and the motor shaft; *B*, the first bearing, between the conducting element and the driven element; *C*, the second bearing, between the driven element and the balancing element; *D*, a friction coupling between the balancing element and the fixed elements of the equipment (the foot plate).

The kinematic analysis of the mechanism, detailed in [2, 12], has been performed by applying the closed vector contour method and aimed at defining its movement law.

Several possible construction versions have been studied in [2], finally the solution presented in this paper being adopted.

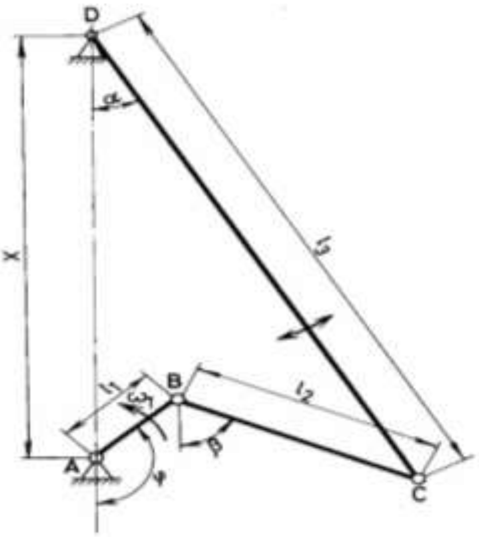

Fig. 4. The kinematic scheme of the driving mechanism of the equipment for the strength test under dynamic torsion loads

The results of the kinematic analysis confirmed the fact that, at the right end of the specimen, firmly fixed to the balancing element, an alternating rotation movement with the required amplitude of ± 5° has been obtained. Furthermore, the angular accelerations of the conducted elements were found to be relatively low and therefore no dynamic analysis was needed, the moments of inertia within the mechanism having low values.

The minimum power input value of the electrical motor, P_m, needed to set in the mechanism, has also been calculated. To this purpose, besides the mass and inertia of the moving components, the rigidity of the specimen at the level of the mobile end has been also taken into account; if assuming a total mechanical efficiency of the mechanism $\eta_t = 0.7$, the resulting power input value was: $P_m = 0.68$ kW.

3. Equipment for the Dynamic Strength Testing under Bending Loads of Copper Pipes Joints

The equipment (shown in the scheme from Fig. 5 and the picture from Fig. 6) designed by the authors to test the dynamic strength under symmetrically alternating bending loads (vibrations) of the joints resulted from pressing or hard soldering of the copper pipes has been conceived – in accordance to the testing procedure described in [1-3] – to submit an U-shaped full-scale test specimen, 6 (made up of several copper pipes and four fittings – two 90 degrees elbows and two couplings) to dynamic (symmetrically alternating) bending loads (vibrations), at room temperature and atmospheric pressure.

One end of the specimen, 8, is rigidly fixed by means of a retaining device, 7, while the other end, 5, is subjected to an alternating movement having a constant specified amplitude (± 1 mm) and a specified frequency (20 Hz), during a specified number of loading cycles (10^6), as indicated in the testing procedure. The equipment is provided with an electrical motor, 2, having a controllable device with eccentric, 3, which induces the alternating bending of the end 5 of the specimen 8.

The main elements of the testing equipment conceived by the authors are briefly described below:

- a frame, 1, on which all the other components are rigidly fixed by means of retaining devices;
- an electrical driving motor, 2, provided, at the driving shaft, with an eccentric device, 3, fitted with a link having a controllable position; the motor is also provided with a device able to record the number of working cycles;
- a mechanism 4, transmitting the motion from the driving shaft of the motor 2 to the right end, 5, of the specimen, 6; the mechanism 4 is made of the following elements:
    - the device with eccentric, 3, on whose link there is a bearing (the first kinematic coupling of the mechanism),
    - an actuating rod, fixed at one end to the bearing housing and having at the other end a special screw,
    - a device with rectilinear reciprocating movement, conveying the motion to the specimen, made up of two blades providing the fixture of the specimen by means of two interchangeable bushings,
    - a guiding blade for the device with reciprocating movement, provided with a bronze slide bearing, fixed to the frame 1;
- a device 7, made up of two fishing sockets and two blades (the left one being fixed to the frame 1 by means of a support), rigidly fixing the left end, 8, of the specimen, 6.

An electrical actuator mechanism has been selected for the conceived equipment, in the most convenient version (from an economic point of view, taking also into account the reliability and its ease of use) of a three-phased induction motor. The high vibrations frequency necessary for the testing of the specimen does not require the use of a speed reduction unit, the actuator mechanism being directly fixed to the shaft of the motor. While the equipment is functioning, the right end of the specimen is subjected to a rectilinear reciprocating motion by means of the actuator mechanism, while the left end remains fixed. The amplitude of the movement can be adjusted by modifying the position of the link with respect to the semi-coupling fitted to the shaft of the actuator mechanism.

The design process of the equipment for the dynamic strength and tightness testing under bending loads, detailed in [2], has taken into account the following criteria:

- the adoption of the simplest kinematic scheme (an actuator mechanism with the smallest number of kinematic elements) and at the same time of the most reliable one;
- the construction of the simplest equipment possible, on which the specimen can

be fixed rapidly and easily;

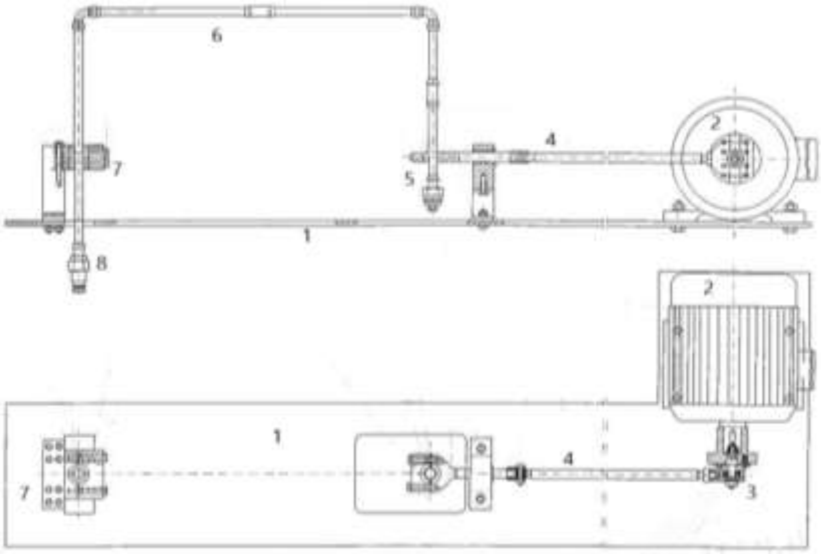

Fig. 5. Scheme of the equipment for the strength test under symmetrical alternating bending loads (vibrations) of copper pipes joints:
1 – frame; 2 – electrical motor; 3 – eccentric device; 4 – motion transmission mechanism; 5 – right end of the specimen; 6 – U-shaped full-scale specimen; 7 – retaining device; 8 – left (fixed) end of the specimen

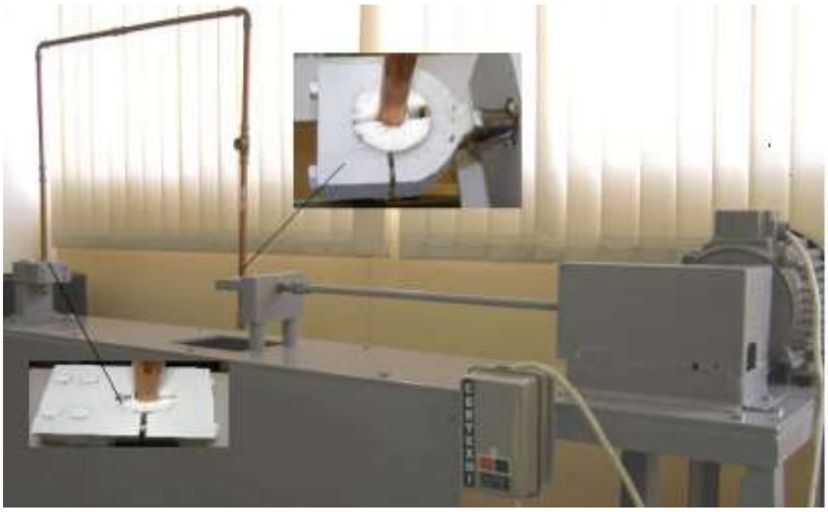

Fig. 6. Picture of the equipment for the strength test under symmetrical alternating bending loads of copper pipes joints

- the construction of the retaining devices of the specimen, so that they should not produce a fracture / failure in this area; practically, the length of the bushings and of the blades was initially established by assessing the contact pressure exercised on the copper pipes of the specimen, so that their surface should not be damaged;

- the assurance of a high rigidity of the equipment; to this aim, the retaining blades of the fixed end of the specimen have been oversized.
- the selection of the materials from which the equipment components have been manufactured aimed at obtaining the required mechanical strength properties in the cheapest way possible; as the stress to which these elements are submitted is quite low, carbon steel has been selected.

After conceiving a first draft of the equipment, its main elements were designed, as detailed in [2], using the typical formula for simple loads and taking into account the main loads acting upon them – those resulting from the weight of the sustained elements and those induced by the actuator mechanism (assessed by means of the kinematic and dynamic analysis of this one, presented below). The standardized elements (bearing, bolts, nuts) were adopted on the basis of the indications of the standards, taking into account the loads acting upon them.

The result of the testing procedure is considered to be positive and the tested type of assembly is considered to be compliant if, after the test, the specimen keeps its tightness. To this purpose, the specimen is finally submitted to a tightness test under internal pneumatic pressure, at room temperature (using the set up shown in Fig. 7), following the procedure 2 as described in [1].

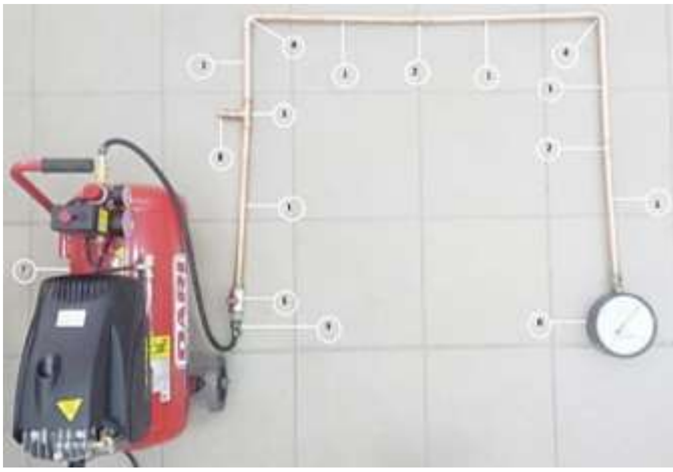

Fig. 7. Tightness testing of the U-shape specimen at internal pneumatic pressure:
1 – copper pipes, 2 – fittings, 3 – tee, 4 – elbows, 5 – copper connector, 6 – pressure gauge,
7 – compressor, 8 – cap, 9 – nipple

In order to analyse the actuator mechanism conceived for the equipment, it has been assimilated to a crank and connecting rod assembly as shown in the kinematic scheme from Fig. 8.

The three kinematic elements of the considered model of the mechanism are the following:

- The leading element, *AB*, which corresponds to the device with eccentric fitted to the driving shaft of the motor, made up of a semi-coupling, link and retaining elements. Its length, *r*, if following the requirements of the testing procedure, shall have the value: $r = 1$ mm. The angular speed of the leading element, ω_1, shall correspond, according to the testing procedure, to a frequency $f = 20 \pm 2$ Hz and therefore its highest value shall be: $\omega_1 = 140$ rad/s.

- The connecting rod element, *BC*, which practically corresponds to the actuating rod and to the elements connected to this one. Its adopted length was $l = 1000$ mm (based on the kinematic analysis of several possible values).
- The link element, point *C*, made up of blades and bushings, fixing elements and bracket. Its motion law is the same with the one of the right end of the specimen.

The motion transmission mechanism has the following kinematic couplings (see Fig. 8): A, rotation coupling between the leading element and the driving motor; *B*, a ball bearing, rotation coupling between the leading element and the connecting rod; *C*, a special screw, rotation coupling between the connecting rod and the link (in order to avoid the functional complications due to the fitting of a bearing into this coupling, the solution of an actuating rod with a relatively great length *l* has been preferred); the translation coupling between the link and the guiding blade.

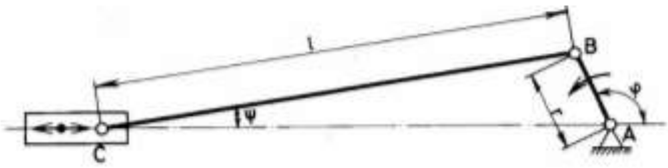

Fig. 8. The kinematic scheme of the actuator mechanism of the equipment for the strength test under dynamic bending loads

The kinematic analysis of the mechanism has been performed by means of the application of the closed vector contour method and aimed at defining its motion law. Several possible versions have been studied in [2], the presented solution being finally adopted.

The results of the kinematic analysis shown in [2, 13] confirmed that, at the right end of the specimen, firmly fixed to the link element, an alternating displacement with the required amplitude (± 1 mm) is obtained. Furthermore, for the adopted length of the connecting rod, $l = 1000$ mm, very small values for the angle ψ (see Fig. 8) are obtained and therefore there was no need for a joint between the connecting rod and the bracket.

As the leading element has an invariable angular speed, $\omega 1$, there are no moments of inertia acting upon it. Due to the very small values of the angle ψ, the same statement is valid for the connecting rod. In addition, the maximum value of the force of inertia which appears in the link area is relatively small and therefore there was no need for special elements in order to counterbalance the analysed equipment.

The minimum power output necessary for the driving motor has also been assessed, based on the mechanical work required for the proper functioning of the mechanism (calculated taking into account the mass and the inertia of the moving components and the rigidity of the specimen at its mobile end). If assuming an efficiency of the mechanism with the value $\eta = 0.7$, the minimum required power output was found to be $P_m = 0.51$ kW.

4. Equipment for Testing the Operating Capacity at High Temperatures of Copper Pipes Joints

The equipment (shown in the scheme from Fig. 9) designed and built by the authors to test the operating capacity at high temperature of the joints resulted from pressing or hard soldering of the copper pipes has been conceived to submit a full-scale specimen, 7 (made up of a fitting and two copper pipes), heated at a constant, high temperature (650 ± 10 °C), for a specified duration (30 minutes), to a specified nitrogen internal pressure (5 ± 0.5 bar). The technical details of the procedures are also presented in [1-3].

A compressor, 1, supplies and maintains the specified constant nitrogen pressure in the specimen, 7, while a gas flow meter, 2, is fixed between the compressor and the specimen by using threaded connectors. The test pressure is measured using a pressure gauge, 8, fitted at the other end of the tested specimen by means of threaded connections. In order to purge the air from the specimen, a purging valve, 10, and a nitrogen gas cartridge detector, 9, are fitted after the pressure gauge at the end of the specimen. Mounting support bands, 11, with threaded rods are used to hold the gas meter, specimen and pressure gauge in position on the frame of the equipment.

The specimen is filled with nitrogen and placed in the heat source chamber, 5, of the electric oven, 6, where it is heated at the specified temperature. A thermal coupling temperature probe, 4, positioned within the heat source chamber, measure its temperature and the real-time temperature reading is shown on a temperature controller display panel, 3. During testing, the gas meter is used to measure the amount of gas losses that may occur due to partial/total failure of the specimen integrity. The tested copper pipe and fitting assemblies are considered compliant to high temperature operation requirements if no gas flow loss occurs or the gas leaks are below 30 dm^3/h.

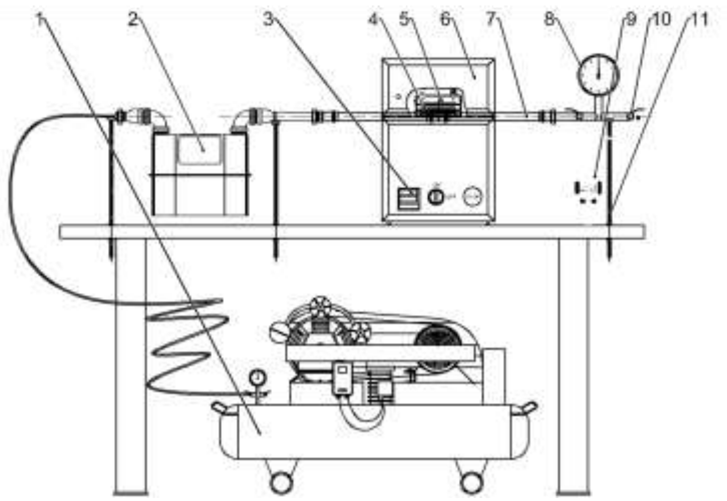

Fig. 9. The kinematic scheme of the actuator mechanism of the equipment for the strength test under dynamic bending loads

A more detailed description of the equipment from Figure 9 can be found in [14-26], where the testing procedure is described in detail and the experimental reliability trials performed to evaluate this equipment are also commented.

5. Conclusions

The present paper describes the equipment conceived and built within the Petroleum-Gas University of Ploiesti for testing the operating capacity at high temperature and the strength and tightness testing under dynamic torsion loads and under symmetrically alternating bending loads (vibrations) of the joints of the pipes and fittings manufactured from copper, designed to be used within the natural gas installations.

The equipment has been constructed in accordance with the testing procedures, described in [1-3], for the quality assessment of the assembly technologies of the joints of copper pipes and fittings. The advantages of the use of these technologies within the natural gas supply installation are also presented in [1-3].

In order to validate the solutions selected for the equipment designed by the authors, a complex testing program has been carried out based on the developed quality assessment procedures, by using full-scale specimens assembled by cold pressing, made up of copper pipes and fittings having nominal diameters ranging between 15 and 64 mm. The results of this testing program have certified our design solutions and the quality assessment procedures developed.

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