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Vacuum technology — Turbomolecular pumps — Measurement of rapid shutdown torque

Technique du vide — Pompes turbomoléculaires — Mesurage du couple d'arrêt rapide

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 27892 was prepared by Technical Committee ISO/TC 112, *Vacuum technology*.

Introduction

A rotating turbomolecular pump or molecular drag pump has a large amount of energy stored in the rotor due to the high rotational frequency. If the rotor breaks, this energy is released in a very short time and there is the possibility of rupture of the casing of the turbomolecular pump. A large reaction torque is also generated on the pump housing and there is a possibility that the bolts that fix the turbomolecular pump might break.

This International Standard is based on results compiled in studies of these possibilities and has been drafted as a measurement method by turbomolecular pump manufacturers with the aim of improving the safety of users.

The core contents of this International Standard are the test methods for rapid shutdown torque measurement of turbomolecular pumps and molecular drag pumps.

The term “turbomolecular pump” used in this International Standard is generic and includes molecular drag pumps and pumps which contain both technologies on the same shaft.

Vacuum technology — Turbomolecular pumps — Measurement of rapid shutdown torque

1 Scope

This International Standard specifies a method for the measurement of rapid shutdown torque (destructive torque) of turbomolecular pumps in which gas momentum is produced by axial flow type blades and/or helical channels. The main forces leading to failure of turbomolecular pumps are torques around the rotational axis. Other insignificant forces and moments that can occur lie outside the scope of this International Standard.

There are two kinds of failure: rapid shutdown by whole burst and softer crash of rotor. This International Standard applies to both. The same measurement method can be used for turbomolecular pumps and molecular drag pumps.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3529-2, *Vacuum technology — Vocabulary — Part 2: Vacuum pumps and related terms*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 3529-2 and the following apply.

3.1
inlet flange
turbomolecular pump inlet suction flange for connecting and fitting on to the vacuum vessel that is to be evacuated

3.2
rotor
rotational body
rotational parts
⟨vacuum pumps⟩ assembly, composed of shaft, rotor body and rotor blades, which is supported by bearings and is driven by a motor

3.3
rotor blade
turbine blade
rotating blade
⟨vacuum pumps⟩ part of a pump which rotates with a peripheral speed close to the speed of sound and which imparts a vacuum exhaust action to the pump, analogous to axial flow type turbine blades

3.4
rotor body
cylinder part of rotor
rotor hub
⟨vacuum pumps⟩ rotor assembly excluding the rotor blades

3.5
centrifugal destruction
split caused by centrifugal force
rupture caused by centrifugal force
failure occurring in the rotor body through circumferential tensile stress above the marginal value due to the centrifugal force acting on the rotor when operating

3.6
destructive test
rotor destructive test
test of the safety of the turbomolecular pump body and measurement of the destructive torque by causing the rotor body of the turbomolecular pump (burst test) or the rotor blades of the turbomolecular pump (crash test) to fail

3.7
destructive rotational frequency
rotational frequency of the rotor when the rotor body fails in the test

3.8
notch machining
machining carried out on all or a part of the rotor prior to destructive testing to form a notch so that an appropriate stress concentration occurs in the rotor body so that failure occurs in the vicinity of the rated rotational frequency separately stipulated for the rotor body during destructive testing

3.9
destructive torque
shutdown torque
rapid shutdown torque
rotational torque acting on or transmitted to the inlet flange fixing member side or base fixing side during failure of the rotor body by centrifugal force in destructive testing

4 Symbols, definitions, and units

Symbol	Definition	Unit
A	Cross-section of compression bar	m^2
d_1	Internal diameter of short tube	m
d_2	External diameter of short tube	m
E	Young modulus of elasticity of lengthwise direction of compression bar	Pa
F_n	Measured force	N
G	Modulus of rigidity of short tube	Pa
I_p	Initial moment of inertia of rotor around rotational axis	kg m^2
i	Compression bar number or force sensor number	
n	Rotational frequency	Hz
r	Location radius of compression bar or force sensor	m
T	Rapid shutdown torque	Nm
t	Time	s
ε	Measured strain	
ω	Angular velocity	rad/s

5 Destructive test methods for turbomolecular pumps

5.1 General

There are two kinds of failure: rapid shutdown by whole burst and softer crash of rotor. Pumps are fixed either at the inlet flange or the pump base. There are thus two kinds of destructive test equipment (see 5.4). The more suitable test method should be selected by the manufacturer based on the intended use of the product.

5.2 Items to be checked

WARNING —The destructive tests listed below are dangerous and adequate safety measures should be taken when carrying them out.

To ensure safety, measure rapid shutdown torque. This method is the only recommended method. The torque obtained by this method is not always the maximum value, but one value.

Check the following items:

a) the value of the destructive torque;

b) that the pump mounting uses the stipulated fitting and is safe;

c) that the pump housing is safe.

5.3 Test conditions for burst and crash (failure of rotor body and rotor blades)

The destructive test conditions are as follows.

5.3.1 Destructive test method (burst)

5.3.1.1 The rotor is deemed to fail when the rotor body or the main shaft fails.

5.3.1.2 The procedure involves notch machining of the rotor body or main shaft so that the rotor body fails by centrifugal or external (e.g. a “crash” destructive test method in which rotor or stator blades fail) force in the vicinity of the rated speed. The notch in the main shaft should be located between the rotating motor and the rotor mounting.

5.3.1.3 Make the notch with four or fewer divisions.

5.3.1.4 The rotational frequency at failure should preferably be within ± 5 % of the rated rotational frequency.

NOTE This International Standard does not make stipulations with regard to the division method of rotor body failure in destructive testing.

5.3.2 Torque cell

5.3.2.1 General

There are two types of torque cell, either consisting of a short tube with strain gauges (5.3.2.2) or a stand with compression bars (5.3.2.3). The compression bars have strain gauges or force sensors attached to them.

If a torque cell is used, ensure that plastic deformation of the cell does not occur.

5.3.2.2 Short tube type

5.3.2.2.1 The torque on the cell is measured by strain gauges, which are fitted to the central part of the short tube, as shown in Figure 1. The strain gauges are installed diametrically opposite one another. Figure 2 shows strain gauges in eight places (four sets) at a pitch of 30°. Other examples are shown in Figures 3 and 4. To ensure adequate responsiveness of the measurement system, it is desirable to use gauges with a range of 0 Hz to 10 kHz or more.

5.3.2.2.2 The destructive torque is calculated from the mean value of strain around the circumference at the time of failure.

The relation between torque, T, in newton metres, and strain is given by Equation (1).

$$T = \frac{\varepsilon\, G\, \pi \left(d_2^4 - d_1^4\right)}{8\, d_2} \tag{1}$$

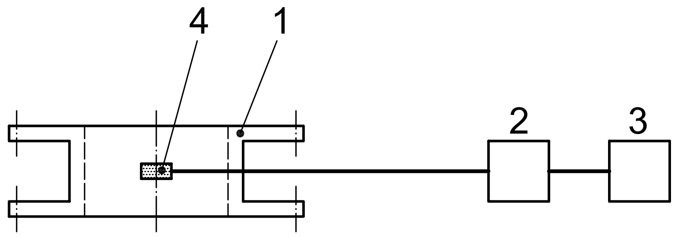
where

ε is the measured strain whose direction is at 45° with respect to the axis of the torque cell;

d_1 is the internal diameter, in metres, of the short tube;

d_2 is the external diameter, in metres, of the short tube;

G is the shearing modulus of rigidity, in pascals, of the short tube.



Key

1 short tube with strain gauges

2 amplifier for strain gauges

3 data recorder

4 strain gauges

Figure 1 — Short tube with strain gauges

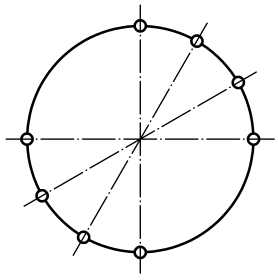


Figure 2 — Example of a pitch of 30°, eight places (four sets)

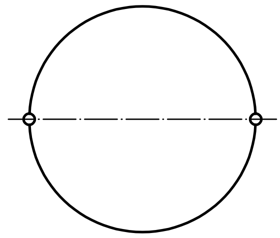


Figure 3 — Example of two places (one set)

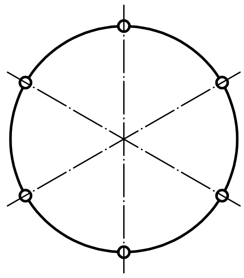


Figure 4 — Example of a pitch of 60°, six places (three sets)

5.3.2.3 Compression bar type

5.3.2.3.1 Compression bars are provided on a stand (see Figure 5) in the direction of action of the pump destructive torque. The bars are set up so that strain gauges or force sensors are compressed by the pump destructive torque. Compression bars with strain gauges are also known as strain rods. The strain rods or the force sensor are fixed to the floor or a base plate by fasteners such as anchor bolts that have sufficient strength.

5.3.2.3.2 The measurement gauge used for the compression bar torque cell is a strain gauge or a force sensor. The strain gauges or force sensors are installed on the compression bars as in 5.3.2.3.1. It is desirable to install compression bars at two to four places at equal intervals around the circumference. To ensure adequate responsiveness of the measurement system, it is desirable to use strain gauges or force sensors with a range of 0 Hz to 10 kHz or more.

5.3.2.3.3 The destructive torque is calculated from the sum of strain or force at the two to four places at the time of failure.

For strain gauges, the torque, T, in newton metres, is related to strain by Equation (2):

$$T = E\,A\,r\,\left(\varepsilon_1 + \ldots + \varepsilon_i\right) \tag{2}$$

where

ε_i is the measured strain;

A is the cross-sectional area, in square metres, of the compression bar;

E is the Young modulus of elasticity, in pascals, of the lengthwise direction of the compression bar;

i is the strain rod number;

r is the compression bar location radius, in metres.

For force sensors, the torque, T, in newton metres, is related to total force by Equation (3):

$$T = r\left(F_1 + \ldots + F_i\right) \quad (3)$$

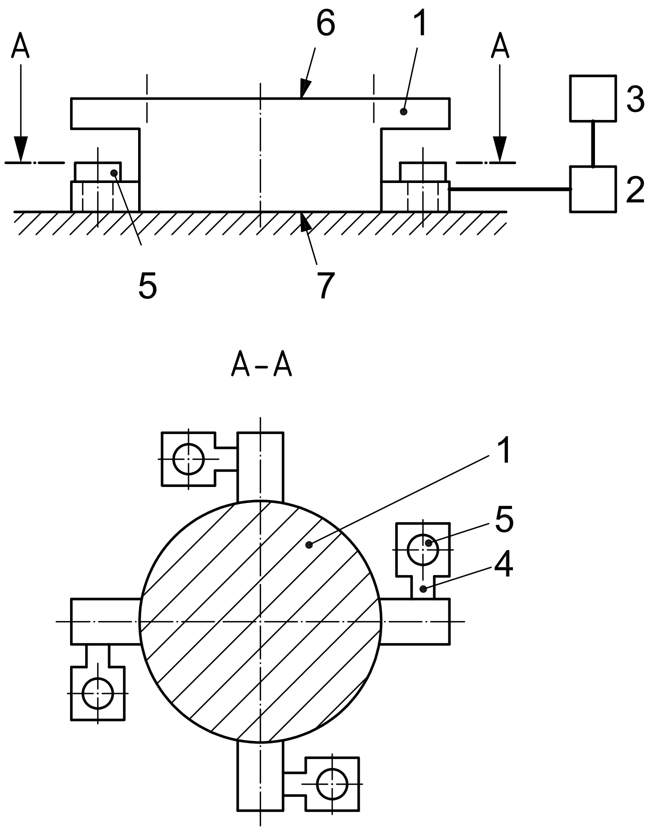
where

F_i is the measured force, in newtons;

i is the force sensor number;

r is the force sensor radius, in metres.

NOTE For the short tube type, the mean value of the output of the strain gauges fitted around the tube is used as the amount of strain. It cannot be proved that the torsion moment acts alone on the short measurement tube, but, by fitting strain gauges in a number of places on the circumference, the reliability of the measurement can be increased. For the compression bar type, a number of compression bar or force sensors are fitted and the total sum of their amount of strain or force is used.



Key

1 stand

2 amplifier for strain gauges or force sensors

3 data recorder

4 compression bars with strain gauges (strain rods) or force sensors

5 anchor bolts for floor or base plate

6 pump side

7 fixing side

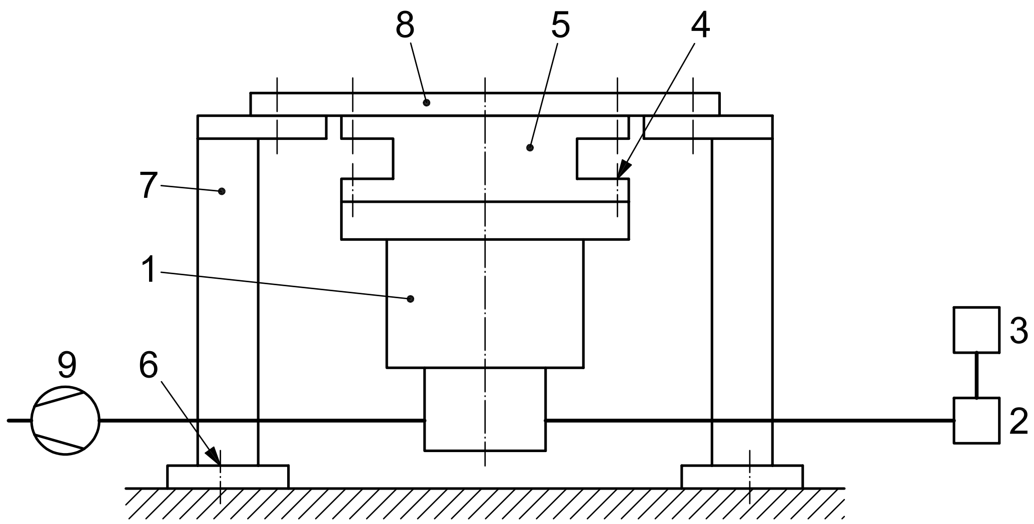
Figure 5 — Stand with compression bars

5.4 Destructive test equipment

5.4.1 Method A

The pump is fixed to the torque cell using the fasteners recommended by the manufacturer. The torque cell is attached to the test frame. The bolts for both these fixings shall have sufficient strength. The test frame is fixed to the floor by fasteners such as anchor bolts that have sufficient strength. The test frame shall neither be deformed by the pump destructive torque nor slip on the surface of the floor. A base plate and a torque cell are fitted to the test frame and the pump inlet flange or the pump base is fixed to the said torque cell by bolts.

The configuration of the equipment for method A is shown in Figure 6, including the measurement of rotational frequency. The test pump is fixed by its inlet flange or its base.



Key

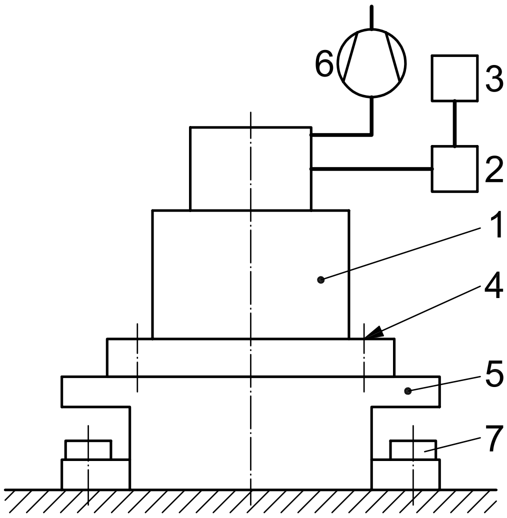
1 turbomolecular pump
2 controller
3 rotational frequency meter
4 bolts
5 torque cell
6 anchor bolts
7 test frame
8 base plate
9 backing pump

Figure 6 — Configuration of equipment for destructive test method A

5.4.2 Method B

The pump is fixed to a torque cell which is fixed to the floor or a base plate so that the pump can twist with the destructive torque. Moreover, plastic deformation caused by the pump destructive torque shall not occur in the torque cell. The torque cell is fixed to the floor or a base plate by fasteners such as anchor bolts that have sufficient strength to prevent movement.

The configuration of the equipment for destructive test method B is shown in Figure 7, including the measurement of rotational frequency. The test pump is fixed by its inlet flange or its base.



Key

1 turbomolecular pump
2 controller
3 rotational frequency meter
4 bolts
5 torque cell
6 backing pump
7 anchor bolts

Figure 7 — Configuration of equipment for destructive test method B

5.5 Destructive test procedures

Start the pump.

It is desirable that the rotor fails at 95 % to 105 % of the rated rotational frequency. If it fails at less than 95 % of the rated rotational frequency, repeat the measurement.

Record the rotational frequency at the time of failure.

Check pump shutdown.

Observe whether there are cracks in the pump case and the state of deformation.

Observe whether there is shearing of the pump inlet flange fitting bolts and the state of deformation of the bolts and flange.

It is desirable to carry out a leak test on the pump body.

In the equipment for either method A or method B, it is necessary to calibrate the resulting destructive torque and the strain or force values measured. The torque is calculated from the strain or force values measured and the rigidity of the measured flange. Consequently, it is necessary to calibrate before the test just what strain or force is measured when a fixed torque is applied to the measurement system. It is desirable to calibrate the destructive test equipment by applying a torque that is larger than the torque that probably occurs at the time of failure, but in this International Standard, the responsibility for calibration lies with the manufacturers and calibration methods are not stipulated.

The rigidity of the stand for the equipment used in method A and method B should be great enough for it not to have any effect on the items being checked in the destructive test. In other words, as little destructive energy as possible should be absorbed by the stand or other parts of the test equipment to minimize any diminution in the measured values.

5.6 "Crash" destructive test method (failure of rotor or stator blades)

Rotor failure mode is taken to mean failure of part of the rotor, e.g. the rotor blades.

The recommended configurations of the test equipment are shown in Figures 8, 9 and 10.

The pump is fixed vertically hanging in a stiff test rig or the pump is fixed vertically to a mounting adaptor.

The decrease in rotor frequency while the rotor is crashing should be used to calculate the torque moment. The rotor frequency can be measured by a photodiode, a laser tachometer or by rotational sensor in the pump (see Figure 8). Possibly a trigger mark should be applied to the rotor. Frequency against time shall be recorded and can be represented in a graph (see Figure 11). Alternatively, the crash torque can be measured with the destructive test equipment (see 5.3.2 and Figures 6, 7, 9 and 10).

The rotor crash is initiated by a projectile, fired from a device (see Figure 12) or a gun barrel (see Figure 9 or Figure 10).

The firing device consists of a pneumatic piston rod cylinder or short-stroke cylinder, a flange with a tube, and the projectile. The projectile is fixed to the piston. On firing, the projectile moves from the idle position (see Figure 13) through a hole in the turbomolecular stator rings to the target position. The projectile is dimensioned so that it strikes at two rotor stages. The projectile consists of a steel cone, a screw (rectangular to the cone) and a thread. Cone and thread are separated by a predetermined breaking point.

Alternatively, a gun barrel can be used to initiate the rotor-stator crash by a shot-in projectile. On firing, the projectile moves from the idle position (see Figure 9 or Figure 10) through the high vacuum flange into the turbomolecular pump. The projectile is dimensioned so that it strikes at two rotor or stator stages. The projectile consists of a steel or aluminium cylinder. The mass and dimensions of the projectile depend on the type of pump under test. Destruction of the first two rotor stator stages causes a chain reaction so that, at least, all of the rotor blades are cut off.

The torque moment, T, is calculated by

$$T = \frac{\mathrm{d}\omega}{\mathrm{d}t} I_p \tag{4}$$

where

ω is the angular velocity;

I_p is the initial moment of inertia of the rotor about the rotational axis;

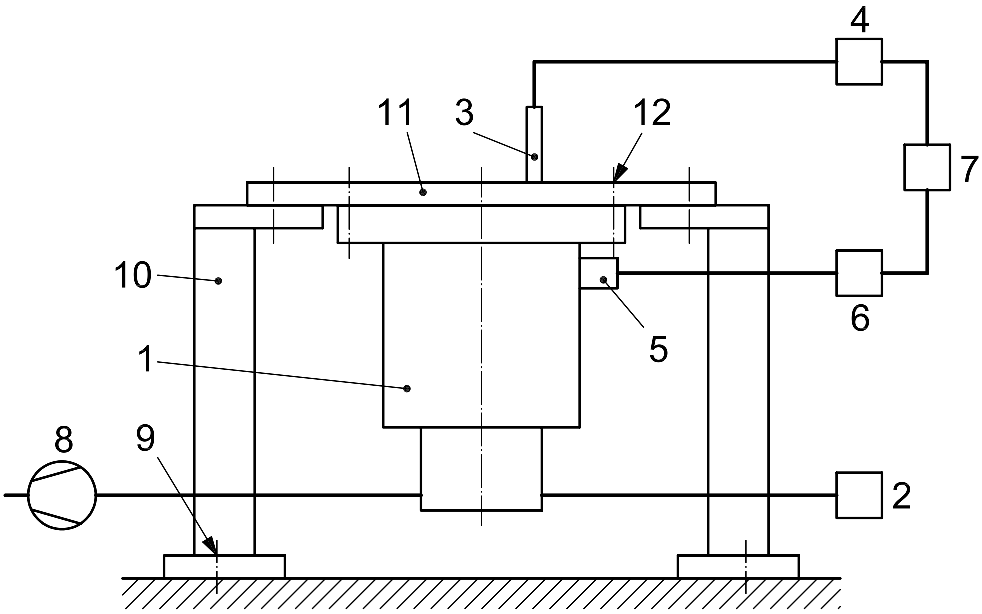
t is time.

$$\frac{\mathrm{d}\omega}{\mathrm{d}t} = \frac{\mathrm{d}n}{\mathrm{d}t} 2\pi \tag{5}$$

where n is the rotational frequency. The term $\mathrm{d}n/\mathrm{d}t$ can be calculated by numerical methods.

NOTE Calculation by Equations (4) and (5) is not precise, because the moment of inertia, I_p, changes when the rotor blades are cut off. However, this method provides the worst-case estimation.

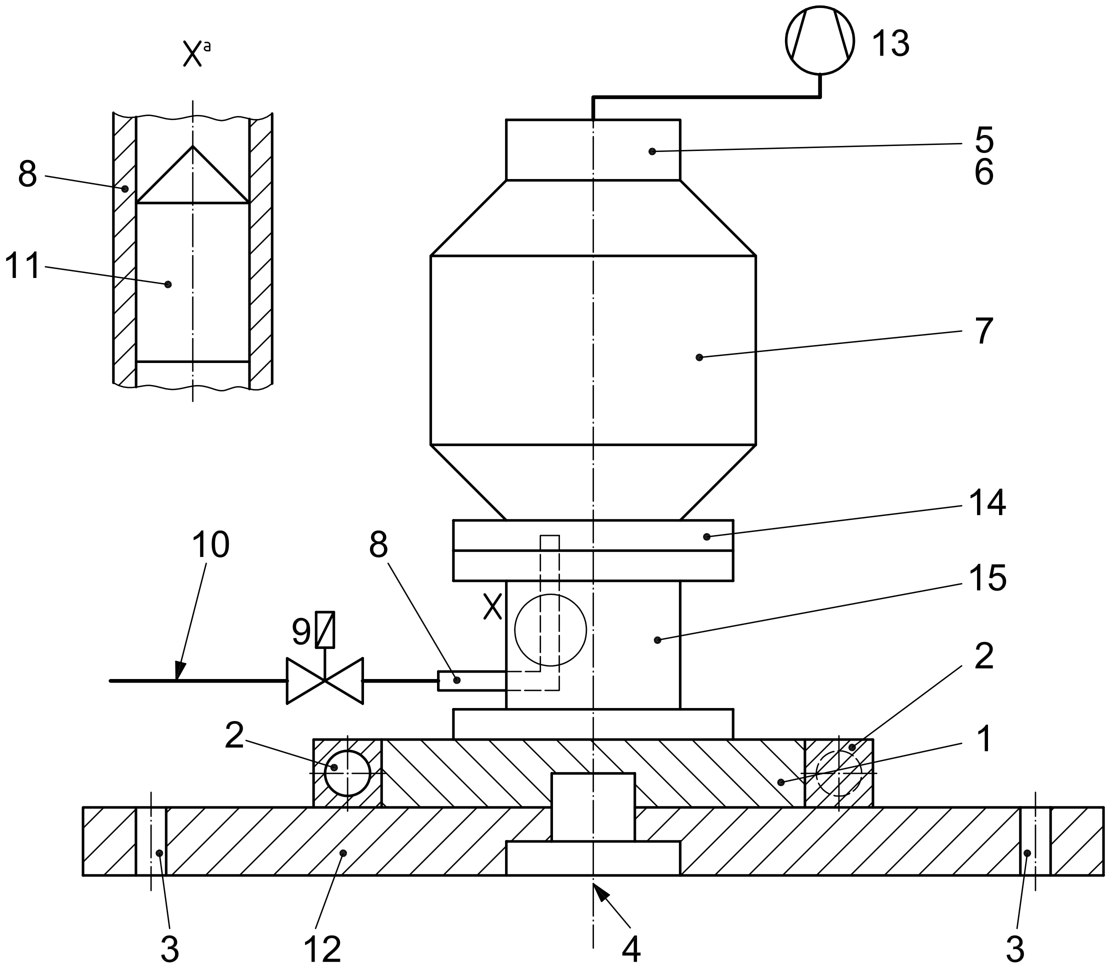
An example of the calculated torque is shown in Figure 11.



Key

1 turbomolecular pump
2 controller
3 rotational frequency sensor (e.g. photodiode)
4 rotational frequency meter
5 projectile firing device
6 regulator, triggering
7 data recorder
8 backing pump
9 anchor bolts
10 base stand
11 base plate
12 pump mounting bolts

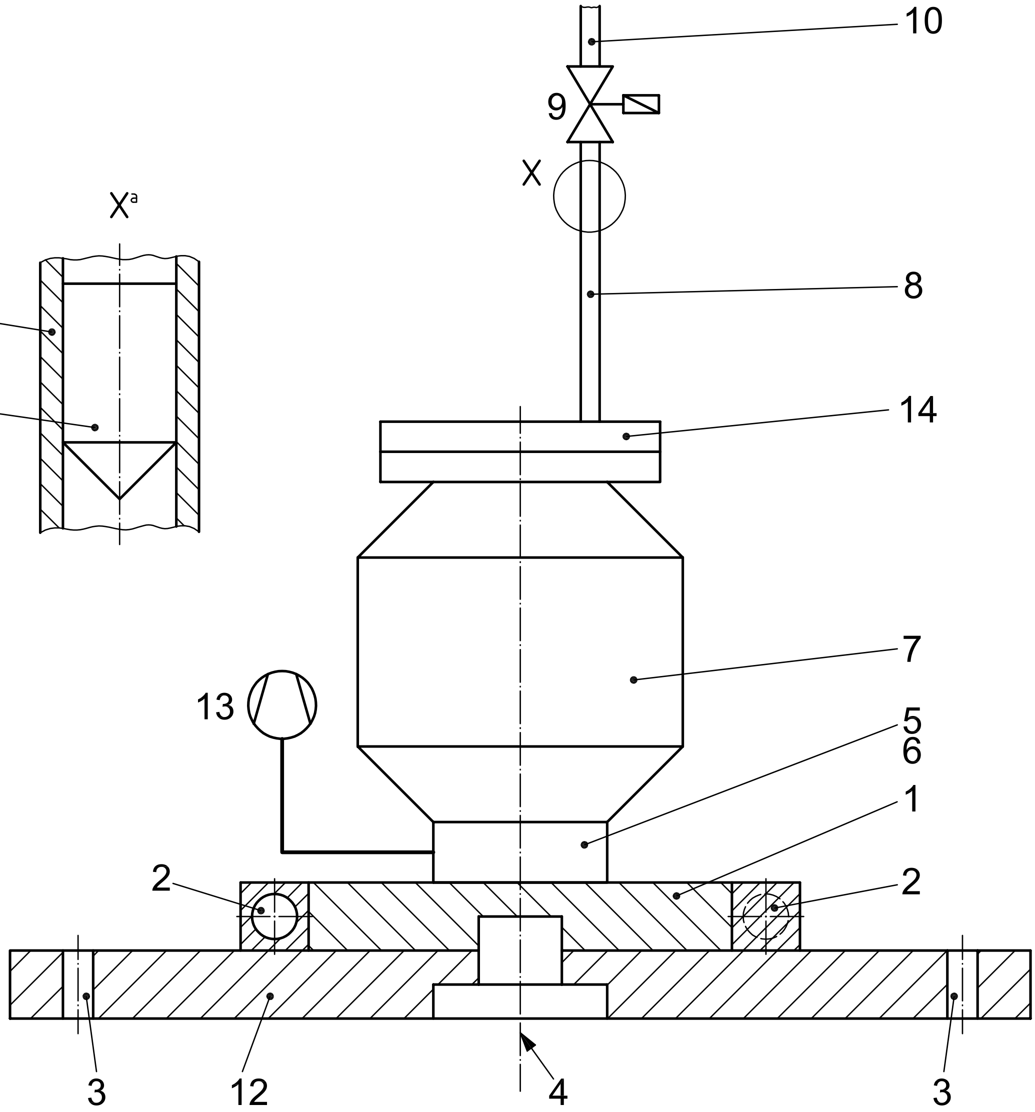
Figure 8 — Configuration of destructive test equipment “crash”



Key

1 mounting adaptor
2 force sensor
3 mounting holes
4 axis of rotation
5 rotational frequency sensor
6 power supply
7 turbomolecular pump
8 gun barrel
9 electromagnetic valve
10 high-pressure air supply
11 projectile
12 base plate
13 backing pump
14 high vacuum flange
15 recipient with integrated gun

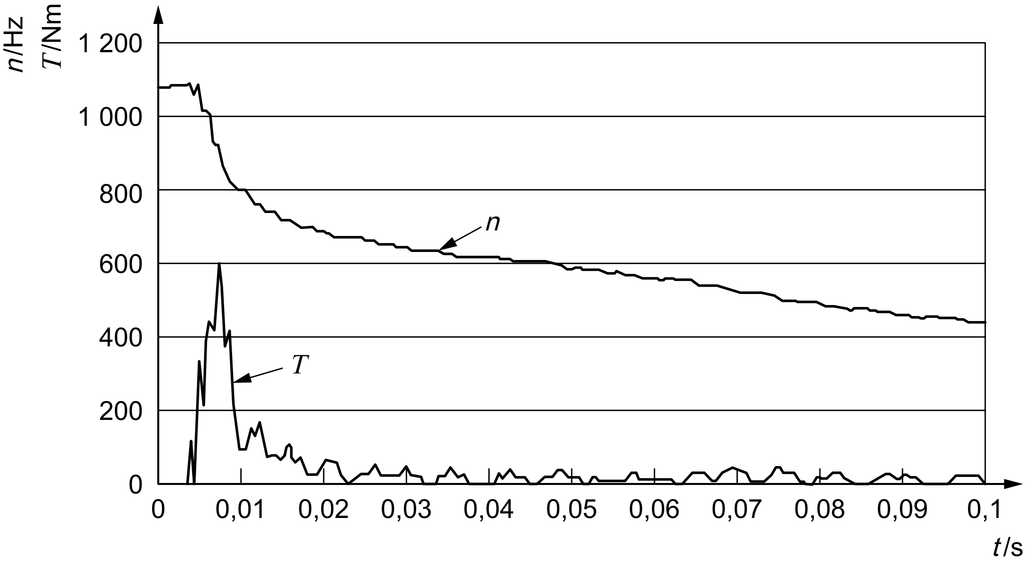
Figure 9 — Configuration of destructive crash equipment C



Key

1 mounting adaptor
2 force sensor
3 mounting holes
4 axes of rotation
5 rotational frequency sensor
6 power supply
7 turbomolecular pump
8 gun barrel
9 electromagnetic valve
10 high-pressure air supply
11 projectile
12 base plate
13 backing pump
14 high vacuum flange

Figure 10 — Configuration of destructive test equipment C



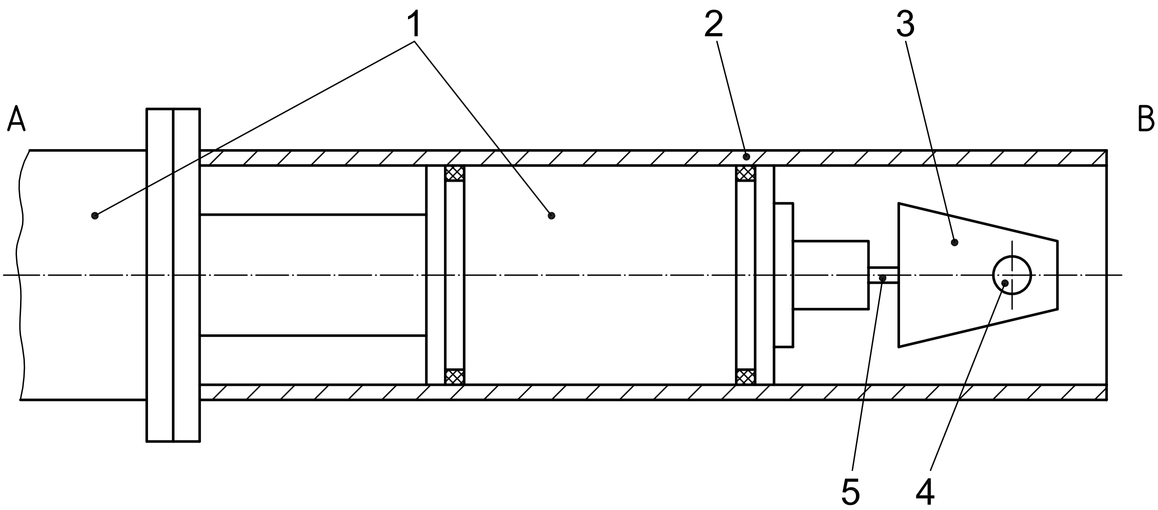
Key

n rotational frequency

T rapid shutdown torque

t time

Figure 11 — Rotational frequency and torque against time



Key

A (to the) piston rod cylinder or short-stroke cylinder

B to the turbomolecular pump

1 short-stroke cylinder

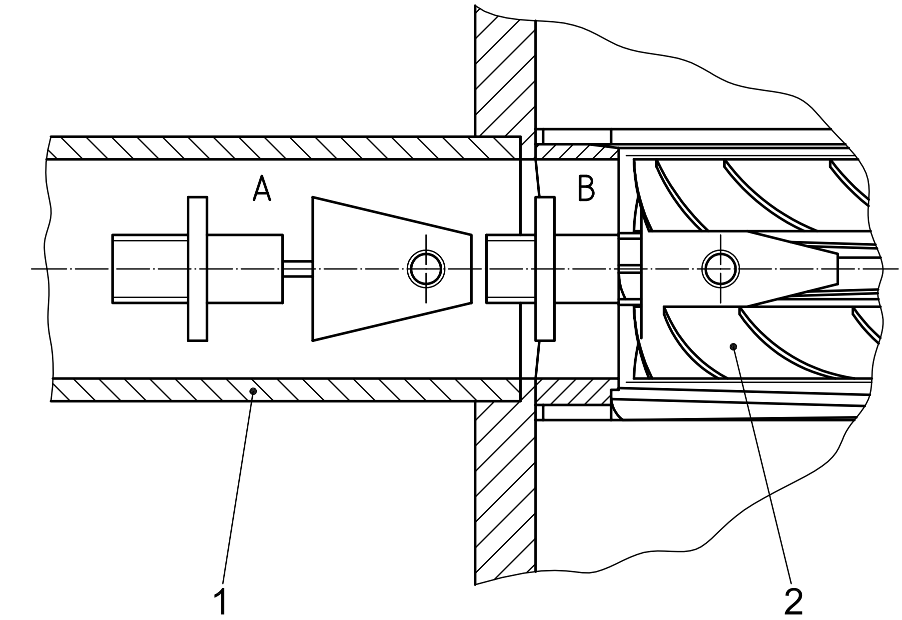
2 flange with tube (part of turbomolecular pump)

3 projectile

4 screw

5 predetermined breaking point

Figure 12 — Projectile firing device



Key

A projectile in idle position

B projectile at target position

1 projectile firing device

2 turbomolecular pump (rotor blades)

Figure 13 — Projectile (without piston) at different positions

6 Test report

The test report shall contain at least the following information:

a) the destructive rotational frequency, expressed in hertz and as a percentage of the rated rotational frequency in hertz;

b) photographs showing the state after failure of the rotor, rotor blades, pump case and all changes to the pump;

c) the destructive torque value as the maximum peak torque value, in newton metres;

d) preferably, a graph of torque against time showing the amount of torque at the time of failure;

e) preferably, the results of the calibration of the torque measurement equipment, indicating any shearing of the pump inlet flange fitting bolts and the state of deformation;

f) indication of any cracks in the pump case and the state of deformation, plus preferably the results of a leak test;

NOTE By the destructive test methods in this International Standard, a check is made of the destructive torque and that there is no problem in mounting the pump by the stipulated method. A check is made that there are no abnormalities in the pump to be tested, including the packaging.

g) the rotation angle of the pump inlet flange after destruction;

h) preferably, information on the rigidity of the test system, e.g. the natural frequency of the test system with the pump around the rotational axis or the result of structural analysis (computer simulation) to simulate motion of the system in the destructive test, for which dynamic and plasto-elastic models are needed for analysis.

Annex A
(informative)

Details to be stated in technical drawings and documents

When the spinning rotor of a turbomolecular pump fails, it is necessary to prevent the turbomolecular pump falling and moving rapidly while rotating. The following items which relate to the safe mounting and operation of a turbomolecular pump shall be considered in the operating manual for the pump and other relevant publications and drawings provided by the pump manufacturer.

A.1 Common items

A.1.1 The dimensions, material, strength classification, and tightening torque value, in newton metres, for the inlet flange and/or base, mounting, and fittings.

A.1.2 Items of limitation to be taken into consideration if someone other than the maker of the turbomolecular pump produces the legs that fix the base.

A.1.3 Pump type.

A.1.4 Form of the inlet flange (e.g. in accordance with ISO 1609 [1]).

A.1.5 Destructive torque measured by the method described in Clause 5 or notes on the design for safe mounting to parts on the pump where rapid shutdown torque is transmitted directly.

A.2 When fixing the pump inlet flange or base with bolts

A.2.1 Items in Clause A.1.

A.2.2 The size, number, material and strength classification of bolts for the inlet flange.

A.2.3 When required, the size, number, material and strength classification of fixing bolts for the base.

A.3 When fixing the pump inlet flange with clamps

A.3.1 Items in Clause A.1.

A.3.2 Number and positioning of clamps.

A.3.3 Size, number, material and strength classification of fixing bolts for the base.

A.4 When a bellows or damper is fitted on the pump inlet flange

A.4.1 Items in Clause A.1.

A.4.2 Items to be noted for strengthening nuts and bolts fitted to the damper.

A.4.3 Size, number, material and strength classification of fixing bolts for the base.

Bibliography

[1] ISO 1609, *Vacuum technology — Flange dimensions*

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