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CRYOGENIC EQUIPMENT FOR LOW-TEMPERATURE HARDENING OF INSTRUMENTS AND MACHINERY FOR NEEDS OF MACHINE BUILDING AND ROLLING PRODUCTION

A temperature-controlled nitrogen cryostat with embedded high-temperature thermally insulated container holder of treated objects has been created for low-temperature hardening of instruments and machinery. To control the surface temperature of rolls a system for cryoblasting of rolls by nitrogen gas-fluid mixture has been designed.

Key words: hardening, thermal treatment, instrument, machinery, rolls, cryostat, cryoblasting system.

It is a well-known fact [1, 2] that the durability of steels having undergone the cryogenic treatment significantly increases as compared with those having been heated only at high temperatures. The products can be exposed to treatment for a time interval from several minutes to hours, days or longer, depending on the chemical composition and geometrical parameters of metallic parts. It is also known that the most effective way is to include the cryogenic treatment into the general process of heat treatment followed by low-temperature tempering instead of using it separately. The heat exposure and holding at high temperature eliminate internal stresses arising in the course of cooling due to differences in thermal expansion coefficients of austenite and martensite, which is especially important for the steels with a large initial share of residual austenite.

Currently, the cryogenic liquids and gases are widely used abroad in metallurgy and machine-building industry. In the CIS countries, this technique has not applied yet in rolling production. In machine building, the low-temperature heat treatment technique allows the engineers to increase 2—5 times without significant capital expenditures the service life of cutting tools, gear reduction unit, and other components operating under heavy dynamic loads and subjecting to severe contact wear. For example, OJSC *Kriokholod* (Ukraine) offers an *installation for thermal treatment of metallic parts UTI 1600-X-2/-50-80* which makes it possible to cool bulky details (120 × 120 × × 80 cm^3) [3] down to a temperature of –80 °C for 90 minutes. However, it is not enough for deep freezing of metal parts having a complete martensitic transformation temperature of –156 °C. The use of cryogenic liquids at rolling mills was patented by *Air Products and Chemicals, Inc.* (USA), the largest producer of industrial gases [4, 5], which uses flexible cryogenic lines for gaseous nitrogen supply to rolling equipment. *Cryotron* (Canada) [6] offers freezers for treating bulky metallic parts at a temperature of liquid nitrogen and customized for heating them up to 300 °C. *Applied Cryogenics* (USA) [7] puts on the market cryoprocessors for treating metallic products within the temperature range from –150 °C to +150 °C with a special temperature control op-

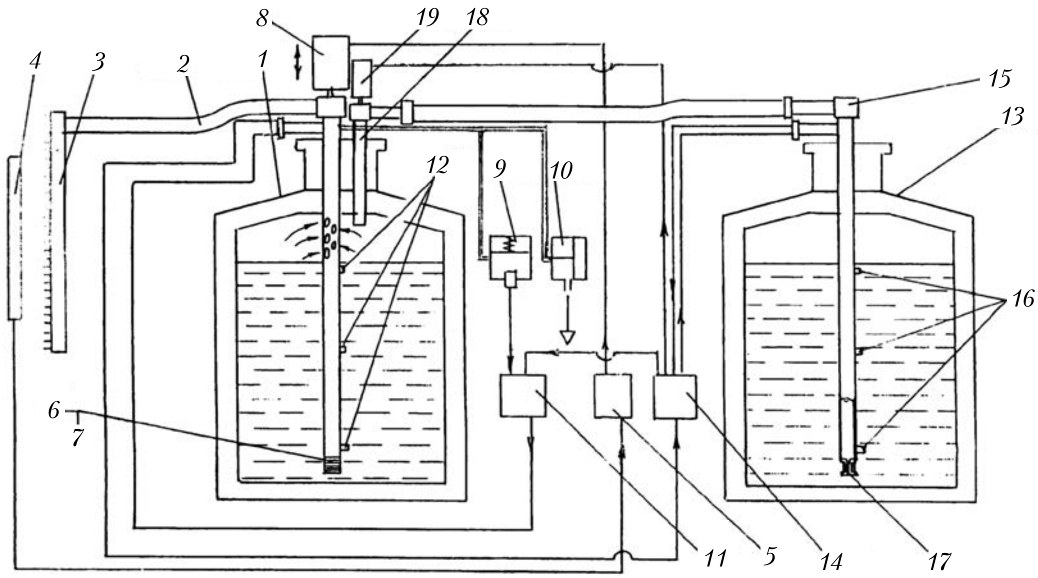

Fig. 1. System for cryogenic treatment of rolls: *1, 13* — vessels for storage of cryogenic fluid; *2, 15* — cryogen feeding siphons; *3* — nipple with nozzles; *4* — remote pyrometer; *5* — temperature controller; *6, 17* — heater evaporators; *7* — throttle valve; *8* — solenoid (actuator); *9* — inductive pressure transducer; *10* — constant pressure valve; *11* — signal amplifier; *12, 16* — discrete fluid level monitoring devices; *14* — fluid level controller; and *18* — receiver tube

tion. In Europe, this cryoprocessor costs over 130 thousand Euros.

In Ukraine, two institutes of the NAS of Ukraine deal with the development of laboratory cryogenic products: Donetsk Institute of Physics and Engineering (Donetsk) [8] and B. Verkin Institute for Low-Temperature Physics and Engineering (Kharkiv) [9]. The liquid or continuous flow cryostats are designed primarily for scientific research and can control temperature in small effective volume within the range from –269 °C (liquid helium) or –196 °C (liquid nitrogen) to the room temperature (20 °C).

Since Ukraine feels the lack of cryogenic equipment and techniques for low-temperature heat treatment of machine parts and components of rolling equipment to strengthen and to improve their wear resistance, in the view of far-reaching prospects for their application the creation of cryogenic equipment for low-temperature hardening of tools and machine parts for the needs of engineering and rolling production is of profound importance.

The problem can be solved in several ways:

1) Creation of temperature controlled cryosystem for treating large parts, such as the rolls of rolling mills;

2) Creation of temperature controlled cryosystem for treating machine parts and tools;

3) Development of methods for treating metal products using the created equipment.

Fig. 1 shows a cryosystem for the treatment of large parts based on flexible cryogenic lines and Dewar vessels with programmable cooling control option.

The cryosystem for cleaning of mill sheets and cooling of rolls has three loops and consists of a) the loop for gas flow supply, temperature control and stabilization, b) the loop for maintenance of pressure of cryogenic fluid vapor; and c) the loop for transfer of backup cryogenic fluid. *The loop for gas flow supply, temperature control and stabilization* (see Figure) contains a working vessel for storage of cryogenic fluid *1*; a feeding siphon *2*; a nipple with nozzles *3*; a remote pyrometer *4*; a temperature controller *5*; a heater evaporator *6* mounted on throttle (lock) valve *7* on the vertical part of feeding siphon having an actuator *8* electrically connected to the temperature controller *5*. *The loop for maintenance of pressure of cryogenic fluid vapor* comprises the feeding siphon *2*, an inductive pressure transducer *9*, a constant pressure valve *10*, a signal amplifier *11*; and discrete level monitoring devices *12*. *The loop for transfer of backup cryogenic fluid* contains a backup transport vessel *13*, a fluid level controller *14*, the vertical part of transport vessel siphon *15* with discrete level-monitoring devices located thereon *16*, and the heater evaporator of transport vessel *17*. The vertical part of siphon *15* with heater-evaporator *17* creates overpressure and supplies working fluid to the vessel *1* through the horizontal part. The horizontal part of transport vessel siphon is directly connected to a receiver tube for cryogenic fluid *18* located on tightly sealed junction of the neck of working vessel *1*. The receiver tube *18* is equipped with an actuator (electromagnet) *19* electrically connected to the cryogenic fluid level controller *14*.

The system operates as follows.

The temperature of nitrogen gas flow is set by the temperature controller. The signal from the pressure sensor through the amplifier triggers the heater-evaporator located below the vertical part of the feeding siphon of working vessel. The heater creates overpressure through which gas enters the horizontal part of siphon and, further, the nipple with nozzles for uniform cooling across the width of treated rolling sheet or roll. The constant pressure in working vessel is kept by the loop for maintenance of nitrogen vapor pressure (feeding siphon, inductive pressure transducer, constant pressure valve, amplifier, and discrete level monitoring devices). The temperature of sheet (roll) is controlled by the remote pyrometer. The imbalance between the set and the actual temperature is compensated by liquid nitrogen periodically supplied to the gas flow through the throttle valve controlled by actuating device (electromagnet) in response to the controller signals. Thus, due to controlling the consumption of nitrogen the temperature of gas flow fed to the nipple with nozzles decreases or increases so that the required temperature is established and kept on the surface of rolling sheet or roll. When the level of liquid nitrogen falls to the average level sensor, the loop for transfer of cryogenic fluid from transport vessel is activated in the working vessel siphon. The signal from the level sensor goes to the level controller which triggers the heater-evaporator *17* in the siphon mounted in the backup vessel. The excessive pressure is created in the vessel, with liquid nitrogen flowing from the backup vessel to the working one. When liquid nitrogen reaches the maximum level in the working vessel the signal from the upper level sensor turns off the heater-evaporator in the transport vessel thereby stopping the transfer of cryogenic fluid. When liquid nitrogen reaches the lower level in the transport vessel the signal from the lower level sensor de-energizes the heater-evaporator. In similar circumstances, in the working vessel, having beeped (to signal that the backup vessel should be filled with liquid nitrogen), the cryogenic fluid level controller turns off the nitrogen supply (the siphon's actuator in the working vessel shuts the throttle valve). The signal from the level controller blocks the amplifier; the heater-evaporator shuts down thereby causing the whole device to cease the operation.

Technical characteristics of the system:

The liquid-gas mixture is fed outward, under a pressure of 1.9 atm., to the rolling mill at a distance of 5 m from the location of transport vessel with liquid nitrogen, through the nipple with nozzles having an option to adjust the consumption rate and the share of fluid in the mixture; the temperature of the surface of rolls is controlled within the range from 493 to 353 K.

Fig. 2 shows the functional diagram of temperature controlled cryosystem for heat treatment of machine parts and tools. The system is based on a nitrogen cryostat containing the evacuated body where there is placed a tank feeder with suspended radiation screens covering the tank feeder, the level indicator, and the pressure sensor connected to the amplifier and the constant pressure valve, a casing with temperature controlled chamber where the temperature sensor is located and which is connected to the tank feeder through the main. The main contains a switching valve, a heater-evaporator, a cryogenic fluid level sensor, and a temperature controller whose input is connected to the temperature sensor and the output is connected to the heater-evaporator. The temperature controlled chamber is designed as a container holder with cover and thermal insulation for the treated objects and with a level sensor and a heater. The cryostat is additionally equipped with a computer connected to the temperature controller. The system can synchronize the operation of cryostat as a whole, with the temperature controller being additionally connected with the heater of container holder.

This makes it possible to reduce, at a given rate, the sample temperature from the room one to the cryogen boiling point and to maintain it for required time. An electric heater can be used to raise the sample temperature to the room one and further to high temperature (the optimal value for steels is up to +300 °C), at a given rate. The container thermal insulation makes it possible to heat the sample without affecting the operation of cryostat elements; therefore, having been exposed to high temperature the samples can be cooled to the room temperature and, if necessary, the heat treatment cycle can be repeated.

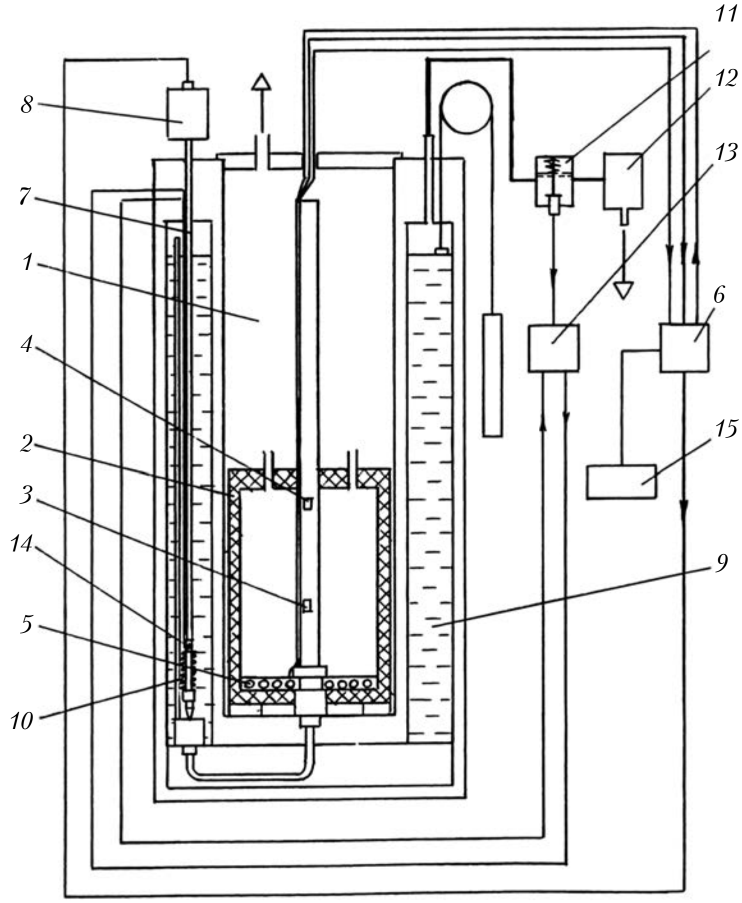

Fig. 2. Functional diagram of temperature-controlled cryosystem for heat treatment of machine parts and tools: *1* — nitrogen cryostat; *2* — container holder of samples; *3* — temperature sensor; *4* — cryogen level sensor; *5* — heater; *6* — temperature controller; *7* — cryogen supply switching valve; *8* — electromagnet; *9* — nitrogen tank; *10* — heater-evaporator; *11* — pressure sensor; *12* — constant pressure valve; *13* — amplifier; *14* — cryogen level sensor; *15* — PC

The nitrogen cryostat has two loops (see Fig. 2) and consists of temperature control and stabilization loop and cryogenic fluid vapor pressure maintenance loop. *The temperature control and stabilization loop* contains cryostat *1*, container holder *2* (with temperature sensor *3*, cryogen level sensor *4*, and heater *5*), temperature controller *6,* and automatic switching valve for cryogen supply *7* controlled by electromagnet *8*. *The loop for maintenance of cryogenic fluid vapor pressure* contains cryostat *1* with fluid feeding container *9*, heater evaporator *10* located on the switching valve *7*, and pressure sensor *11* with constant pressure valve *12*. The pressure sensor is connected to amplifier *13;* cryogen level sensor *14* is located on the switching valve *7*. These loops are functionally and electrically connected through computer (PC) *15* controlling the modes of cryostat operation in accordance with established algorithm.

The cryostat consists of external shell and cryogen tank feeder suspended on thin-walled stainless steel tubes to the shell which bears the suspended radiation screen covering the tank feeder and the elements of the main for cryogen supply to the container holder.

The cryostat casing is made of stainless steel thin-walled tube suspended to the external shell of cryostat and has in its top part a hatch for loading and unloading of container holder to change the treated samples. In the center of its bottom, there is mounted a nipple of the main for gaseous or liquid cryogen supply from the switching valve. Cryogen level in the tank feeder is controlled visually using a float level indicator.

The container holder and its cover are double-walled, made of stainless steel. The container has thermal insulation between the walls; in the center of its bottom, there is mounted a flow divider that divides evenly the cryogen flow between the bottom and a removable perforated disk fastened above the flow divider having a sealer to ensure a tight connection with the nipple while loading the container holder into the casing. The heater is mounted between the bottom of the container holder and the perforated disc. The switching valve has a spring triggering the shutdown of liquid cryogen supply, whereas the electromagnet triggers the activation of supply.

The device operates as follows.

Before removing the container from the cryostat casing it is necessary to remove the hatch. Then, the following steps should be done: to open cover, to load the container with objects to be treated with cryogen, and to place the container in the cryostat; to fill the tank feeder with liquid nitrogen. The level of cryogenic fluid in the tank feeder is controlled visually using a float level indicator; pressure is maintained by the heater evaporator *10* connected to the pressure sensor *11* and the amplifier *13*. If the level of cryogenic fluid in the tank feeder falls to the level of level sensor *14* the heater evaporator *10* shuts down and the beep signals that it is necessary to pour additional cryogenic fluid into the tank feeder.

The required temperature in the container holder *2,* the rate of changing temperature to achieve the required temperature, and the time of holding the treated objects at a given temperature are set through the computer *15*. Nitrogen comes from tank feeder *9* through automated cryogen supply switching valve *7* controlled by electromagnet *8*, to the supply main *18* and to the container holder *2*. As temperature approaches the boiling point of liquid nitrogen, the signal from the temperature sensor *3* switches via the valve *7* the mode of cryogen supply from the gaseous to the liquid phase, with the liquid cryogen entering the container *2*. As soon as cryogen reaches the top level of container, the level sensor *4* triggers giving a signal to the magnet *8* to shut down the cryogen supply valve *7* to stop liquid nitrogen supply to the container. Having held the samples in liquid nitrogen for a given period of time the computer that controls heating of cryogen and its removal from the container raises the object temperature to the room one. As the temperature comes to required value the device changes over to standby mode. The object in the container is held at this temperature for required time, thereafter the signal from the computer *15* through the heater *5* raises, at a given rate, the temperature of container *2* with

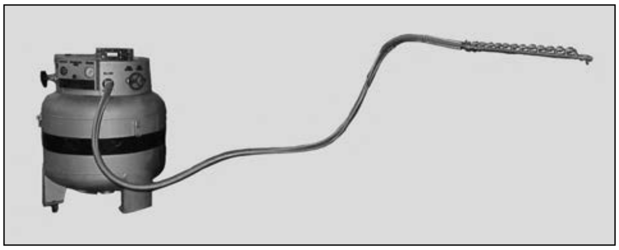

Fig. 3. General view of the roll cryoblasting system

Fig. 4. General view of temperature-controlled nitrogen cryostat

samples to a targeted high value (for example, 300 °C). As temperature reaches the targeted value the heater *5* keeps it for a certain time and thereafter decreases it to the room temperature. After this, the heat treatment cycle is repeated as many times as required.

Technical Parameters of the System

Temperature range.	77–443 K
Accuracy of temperature control inside effective volume of chamber	±1 K
Pattern of temperature change.	Linear
Possible rate of cooling/heating within the range	1–10 K/min
Size of loading space	Diameter 300 mm, length 500 mm
Cryostat operation without cryogen refilling.	24 hours

The treatment of tools and parts by repeated cycles:

1) Cooling from 293 to 77 K at a rate of 1–5 K/min;

2) Holding at a temperature of 77 K during 24 hours;

3) Heating up to 293 K and change of treated parts in the container holder;

4) Heating up to 443 K at a rate of 1–5 K/min;

5) Cooling to 293 K and repetition of cycles with changing treated parts.

Figs. 3 and 4 show the roll cryoblasting system and the temperature-controlled nitrogen cryostat, respectively. The copyright is protected by patents of Ukraine [10, 11].

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КРИОГЕННАЯ АППАРАТУРА ДЛЯ НИЗКОТЕМПЕРАТУРНОГО УПРОЧНЕНИЯ ИНСТРУМЕНТА И ДЕТАЛЕЙ МАШИН ДЛЯ НУЖД МАШИНОСТРОЕНИЯ И ПРОКАТНОГО ПРОИЗВОДСТВА

Для низкотемпературного упрочнения инструмента и деталей машин создан терморегулируемый азотный криостат со встроенным высокотемпературным термоизолированным контейнером-держателем, а для регулирования температуры поверхности валков прокатного стана создана криоустановка для обдувания валков газово-жидкостной смесью азота.

Ключевые слова: упрочнение, тепловая обработка, инструмент, детали машин, валки, криостат, установка для обдувания.

І.П. Жарков

КРІОГЕННА АПАРАТУРА ДЛЯ НИЗЬКОТЕМПЕРАТУРНОГО ЗМІЦНЕННЯ ІНСТРУМЕНТА І ДЕТАЛЕЙ МАШИН ДЛЯ ПОТРЕБ МАШИНОБУДУВАННЯ ТА ПРОКАТНОГО ВИРОБНИЦТВА

Для низькотемпературного зміцнення інструмента та деталей машин створено терморегульований азотний кріостат із вбудованим високотемпературним термоізольованим контейнером-тримачем, а для регулювання температури поверхні валків прокатного стана створена кріоустановка для обдування валків газово-рідинною сумішшю азоту.

Ключові слова: зміцнення, теплова обробка, інструмент, деталі машин, валки, кріостат, установка для обдування.

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