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NEW TEST RIG FOR MEASURING THE FRICTION TORQUE OF GEARBOXES IN EXTREME THERMAL CONDITIONS

NOWE STANOWISKO BADAWCZE DO POMIARU OPORÓW RUCHU PRZEKŁADNI ZĘBATYCH W EKSTREMALNYCH WARUNKACH TERMICZNYCH

Key words: toothed gear, gearbox, friction torque, test rig, extreme thermal conditions.

Abstract: A new test rig for tribological tests was developed and manufactured. It consists of a mobile device for measurement of the start-up friction torque of transmissions, in particular planetary gearboxes, and the friction torque in dynamically steady conditions, as well as a climatic chamber to stabilize the temperature of the tested gearbox in its extreme range: from -50 to +50°C. In the series of devices for tribological tests, developed and manufactured at the Institute, the new test rig is marked with the symbol T-34.

The verification results correspond with the churning losses related to the viscosity characteristics of the lubricating oils. As the temperature increases, both the start-up friction torque and the friction torque under dynamically steady conditions decrease.

Słowa kluczowe: przekładnia zębata, moment rozruchu, moment oporów ruchu, stanowisko badawcze.

Streszczenie: Przedstawiono nowe stanowisko do badań tribologicznych. Składa się ono z mobilnego urządzenia do badania momentu rozruchowego przekładni zębatych, w szczególności planetarnych, oraz momentu tarcia w warunkach dynamicznie ustalonych, a także z komory klimatycznej do stabilizowania temperatury badanej przekładni w skrajnym jej zakresie: od -50 do +50°C. W typoszeregu urządzeń do badań tribologicznych, opracowanych i wytwarzanych w Instytucie, nowe stanowisko posiada symbol T-34.

W ramach weryfikacji działania nowego stanowiska uzyskano wyniki badań momentu tarcia przekładni planetarnych, odpowiadające charakterystyce lepkościowej oleju smarowego. W miarę wzrostu temperatury zarówno moment rozruchowy, jak i moment tarcia w warunkach dynamicznie ustalonych spadają.

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INTRODUCTION

Tribological tests are most often performed on simple model samples **[L. 1–5]**. One of the most important reasons for this approach is cost. Alliston-Greiner emphasizes that model tests on simple samples can be up to a hundred times cheaper than testing machine components or assemblies **[L. 6]**.

Habig **[L. 7]** analysed the advantages and disadvantages of individual research categories. The analysis shows that the parameters of the model tests are clearly distinguished and can be easily maintained at a constant level; however, serious distortions are possible, e.g., due to different heat flow, different tribochemical reactions, different methods of applying the load and different vibrations of the tribosystems, compared with the test conditions during testing machine components or assemblies.

The problem of the relationship between the research on simple samples and the research on the elements of the machines or assemblies is covered by the classification based on the "Heinke chain of tribological tests," included in DIN 50 322 and described, among others, in the works **[L. 8, 9]**. This classification was built on the principle of a gradual reduction in the complexity of the tribosystem and working conditions; model tests on simple samples are of Category VI, and the most demanding and costly field tests – Category I.

In 2021, Łukasiewicz – Institute for Sustainable Technologies (Ł-ITEE), together with other partners of the consortium, completed a R&D project. As a result of the project, two prototype planetary gearboxes for driving mining conveyors have been designed and manufactured – **Fig. 1.**

Innovative material technologies were used for the gears in order to extend the failure-free

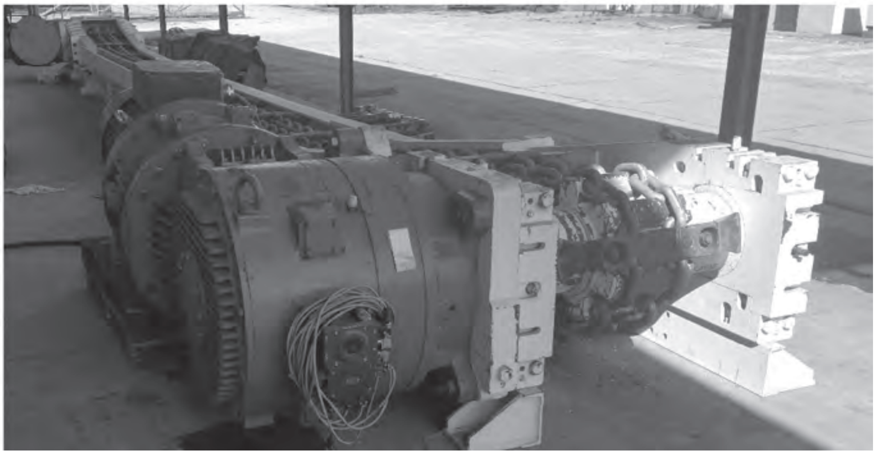

Fig. 1. A mining conveyor with the prototype planetary gearbox
Rys. 1. Przenośnik górniczy z prototypową przekładnią planetarną

operation in difficult operating conditions due to temperature and abrasive contamination **[L. 10]**. One of the tasks of Ł-ITEE was to measure the start-up friction torque of the planetary gearbox and the friction torque after reaching the operating rotational speed of the input shaft (dynamically steady conditions) – in extreme temperatures. Since such tests could not be performed on simple model samples, a new device for tribological tests was developed and manufactured. It is a rig for testing the start-up friction torque of gearboxes and the friction torque in dynamically steady conditions. In the series of types of devices developed and manufactured at Ł-ITEE, the new test rig is marked with the T-34 symbol.

The new test rig consists of a mobile device for testing the friction torque, and a climatic chamber to stabilize the temperature of the tested gearbox in its extreme range: from -50 to +50°C. The chamber allows for heating/cooling the tested gearbox and temperature stabilization in its entire volume.

With regard to the aforementioned classification based on the Heinke chain of tribological tests, research made using the T-34 test rig can be classified as Category III (stand tests of the assembly).

In the literature, one can find various solutions of test rigs for measuring the friction torque of planetary gears. For example, Boni et al. **[L. 11]**, in order to estimate the power losses in the transmission, used the test rig with the measurement of the friction torque only on the input shaft, i.e. similarly to the T-34 test rig. Lundin and Mårdestam **[L. 12],** in order to estimate the efficiency of the transmission, used a test rig with the possibility of measuring the friction torque on both the input and output shafts. In turn, Achtenova **[L. 13]** proposed a rig for testing the efficiency and durability of gears, operating in the back-to back power system. This is the same idea that has been used for many years in the gear research techniques developed by the Gear Research Center (German abbreviation FZG) of the Technical University of Munich **[L. 14]**.

Computer modelling is also often used. For example, Salagianni, Nikolakopoulos, and Theodossiades **[L. 15]** used tribodynamic modelling to estimate friction in the meshing teeth of a planetary gear.

This article presents the T-34 test rig, tested planetary gearboxes, research methodology, and the results of verification tests.

T-34 TEST RIG

The new test rig consists of a mobile device for testing the start-up friction torque and the friction torque in dynamically steady conditions, and a climatic chamber to stabilize the temperature of the tested gearbox in its extreme range: from -50 to +50°C. The chamber allows for heating/cooling the tested gearbox and temperature stabilization in its entire volume.

A photograph of the mobile device for testing the start-up friction torque and the friction torque in dynamically steady conditions is presented in **Fig. 2**.

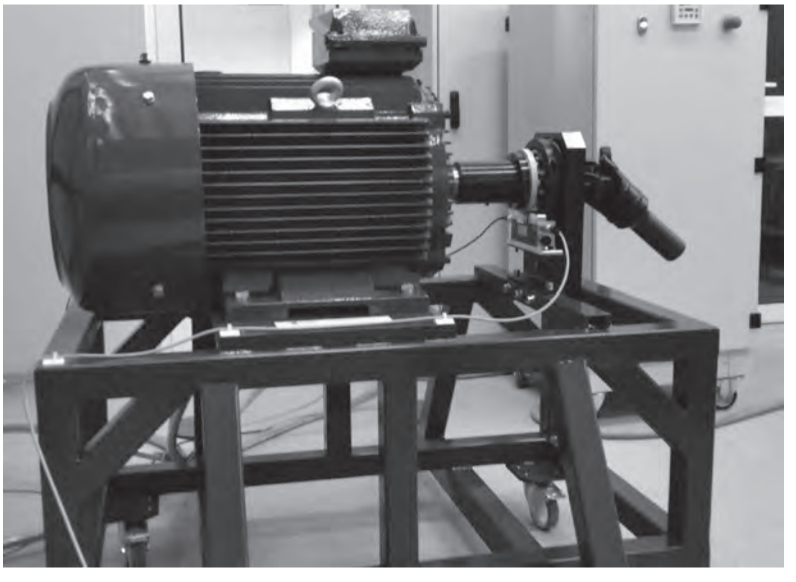

Fig. 2. The mobile device for testing the start-up friction torque and the friction torque in dynamically steady conditions
Rys. 2. Urządzenie do badania momentu rozruchowego przekładni zębatych oraz momentu tarcia w warunkach dynamicznie ustalonych

The developed device is mobile. A high-power (45 kW) asynchronous motor is mounted on the frame moving on wheels. It drives the torque meter (measuring range up to 500 Nm), and via Cardan shaft and a special sleeve the driving torque is transmitted to the input shaft of the thermally seasoned gearbox located in the climatic chamber.

During the start-up and operation at a steady rotational speed (1450 rpm), the torque meter measures the no-load resistance to motion (related mainly to churning due to splash lubrication), and the measurement signals are sent with a sampling frequency of up to 50 Hz to the measuring amplifier and computer. This makes it possible to compare the no-load resistance to motion of gearboxes seasoned in different temperature conditions. For the simplicity of the text, the no-load resistance to motion will be called "the friction torque."

The device is equipped with a control cabinet in which all control elements are located. The most important is the high-power inverter to drive the electric motor. The inverter allows for a soft start-up and gradual increase of the rotational speed, which prevents excess currents in the electrical network in the laboratory.

The motor is turned on from the control panel located on the door of the control cabinet.

A photograph of the climatic chamber is shown in **Fig. 3**.

Fig. 3. The climatic chamber
Rys. 3. Komora klimatyczna

The climatic chamber is a modified version of the KWT-15 chamber, developed and manufactured at Ł-ITEE, adapted, e.g., to the research needs of the T-34 test rig. The adaptation of the KWT-15 climatic chamber consisted in the following:

- Improvement of chamber seals and elimination of thermal bridges, which allowed to obtain the temperature down to -50°C;
- A modification of the system of separating the test chamber and the cooling system by using a movable shutter, which allowed to obtain a temperature of up to +50°C;
- Increasing the load-bearing capacity of the test chamber floor to obtain the load-bearing capacity of approx. 3.5 tons;
- The development and implementation of a new control and measurement system;
- The development and implementation of security systems;
- The developing a new program for the main controller;
- The verification of the operation of the chamber from the point of view of, primarily, the stability of temperature control over a long period of time.

A special support was designed and made for the safe locating of the tested gearbox on the floor of the climatic chamber. A photograph of the support is shown in **Fig. 4**.

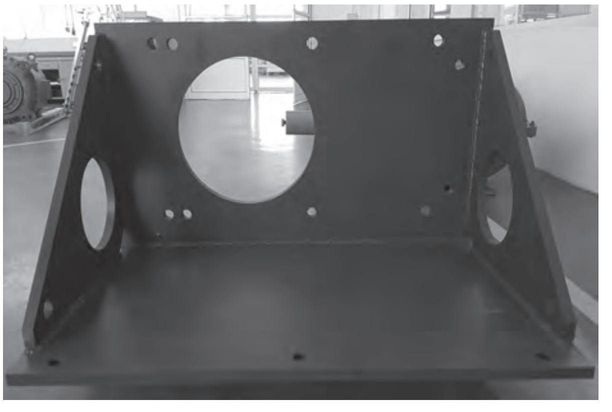

Fig. 4. The special support of the tested gearbox
Rys. 4. Wspornik do posadowienia przekładni

The tested gearbox is attached to the rear wall of the support with a set of bolts. Side holes allow access to the bolt tightening area.

The T-34 test rig in operation is shown in **Fig. 5**.

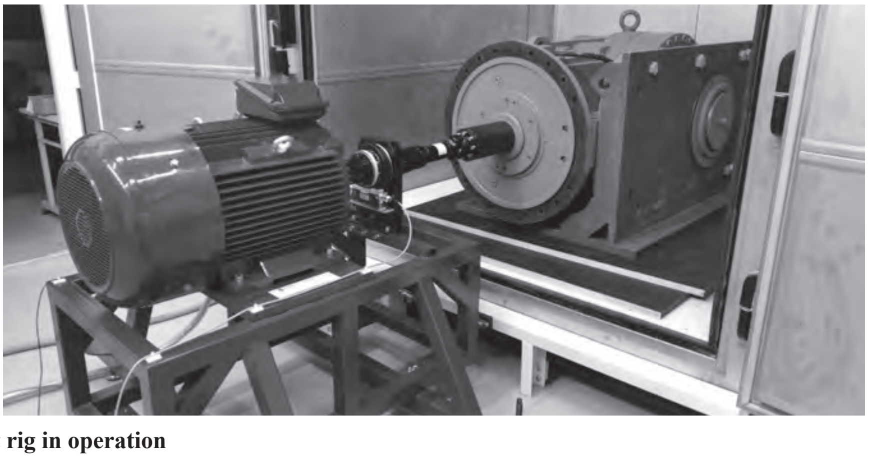

Fig. 5. The T-34 test rig in operation
Rys. 5. Stanowisko T-34 w czasie pracy

The test is performed after opening the chamber door and connecting the mobile device – through a Cardan shaft and a special sleeve – to the input shaft of the gearbox. As the test is relatively short, there is no risk of changing the temperature inside the gearbox unit.

In order to show the method of connecting the mobile device, the cover protecting the Cardan shaft was not installed at the time of taking the photo.

TESTED GEARBOXES

The research concerned two prototype planetary gearboxes with different gear ratios and symbols:

- mKPL-25, i = 33,
- mKPL-25, i = 24, and

the planetary gearbox so far manufactured by Patentus SA from Pszczyna – KPL-25, i = 33.

One of the mKPL-25 gearboxes is shown in **Fig. 6**.

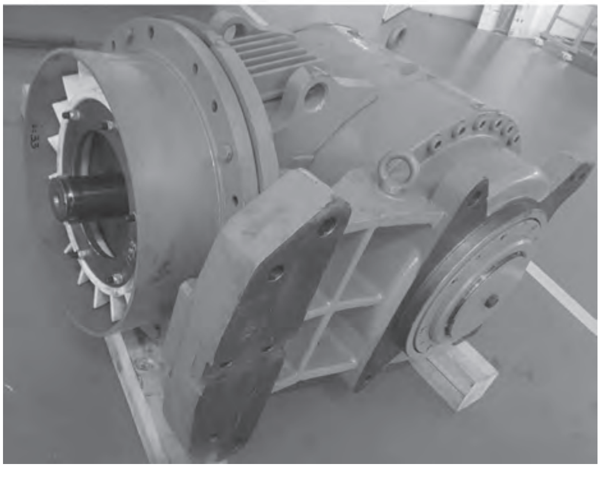

Fig. 6. The prototype planetary mKPL-25 gearbox
Rys. 6. Prototypowa przekładnia mKPL-25

In the mKPL prototype gearboxes, apart from the ring gear, all gears were made of nanobainitized 35CrMnSiA steel. The wheel of the bevel gear was covered with W-DLC/CrN coating. The lubricating oil was a commercial industrial gear oil of viscosity class 320 with a PAO (polyalphaolefin) synthetic base.

Apart from the ring gear, the KPL gearbox had all gears made of 18CrNiMo7-6 steel. No coating was applied. The lubricating oil was a commercial industrial gear oil of viscosity class 320 with a mineral base.

TEST METHODOLOGY

During the test, the sequences of changing the rotational speed of the gearbox input shaft were applied, as it is shown in **Fig. 7**.

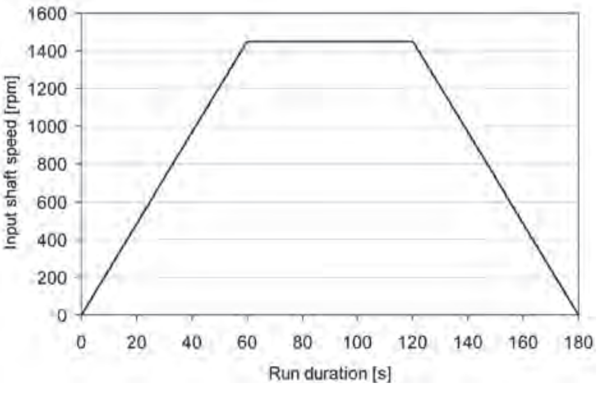

Fig. 7. The sequences of changing the rotational speed of the gearbox input shaft
Rys. 7. Sekwencje zmiany prędkości obrotowej wału wejściowego przekładni

The start-up of the gearbox took 60 seconds. Then, for the next 60 seconds, the rotational speed of the input shaft of the gearbox was stable – at the level of 1450 rpm. This phase was followed by turning off the motor and self-braking – for approx. 60 s.

A typical friction torque during start-up is shown in **Fig. 8**.

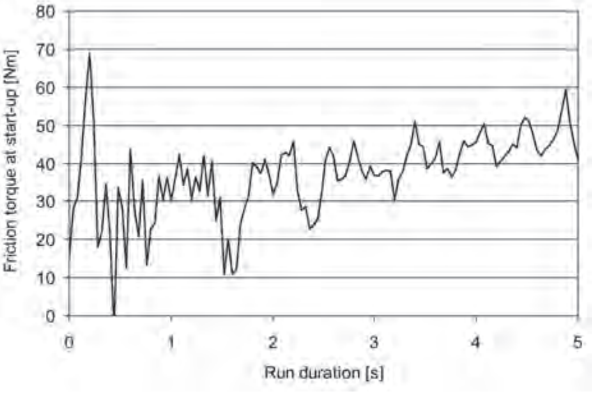

Fig. 8. A typical friction torque during start-up
Rys. 8. Typowy przebieg momentu tarcia w czasie rozruchu

In the case of the gearbox start-up friction torque, the first 2 s of the test were analysed. During this time, the measured values of the friction torque were averaged.

A typical friction torque during tests in dynamically steady conditions is shown in **Fig. 9**.

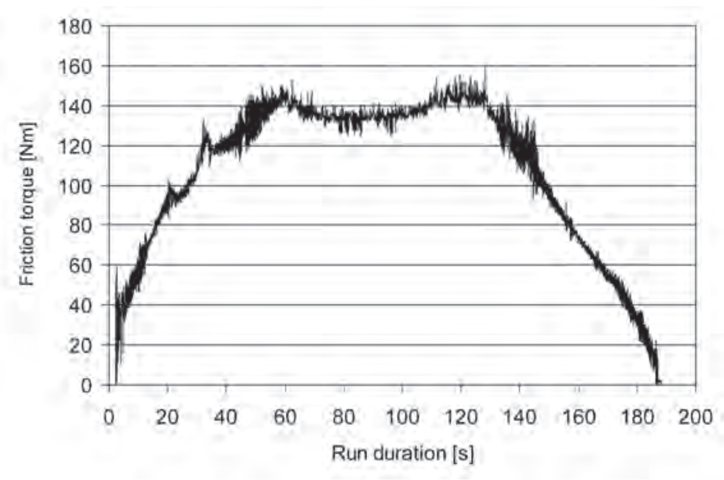

Fig. 9. A typical friction torque during tests in dynamically steady conditions
Rys. 9. Typowy przebieg momentu tarcia w czasie badań w warunkach dynamicznie ustalonych

During 60 s of tests in dynamically steady conditions (from 60 to 120 s), i.e. at a constant rotational speed of 1450 rpm, the measured friction torque was averaged.

Due to the rheological characteristics of the lubricating oils used in the gearboxes (the freezing point of the mineral oil used is -12°C), the thermal resistance of the KPL gear seals, and the operating range of the torque meter, the tests were performed within the limits of -10 to +50°C.

In order to achieve the desired temperature in the entire volume of the gearbox, before the first test, the gearbox was seasoned in the climatic chamber for a minimum of 2 days. Subsequent tests were performed at intervals of at least 7 hours.

The tests were performed at intervals of 10°C. Three runs were performed at each temperature. It was observed that, in subsequent runs, the friction torque decreased, which is due to the decrease in oil viscosity caused by the heat of friction. Therefore, in order to maintain the comparability of the results, the results of the run No. 1 were taken into account when analysing the start-up torque, while the results of the run No. 2 were taken into account when analysing the friction torque under dynamically steady conditions.

During the tests, the braking system was not used to achieve the no-load test conditions.

TEST RESULTS

The effect of the temperature on the frictional torque during the start-up of the planetary gearboxes is shown in **Fig. 10**, and in dynamically steady conditions – in **Fig. 11**.

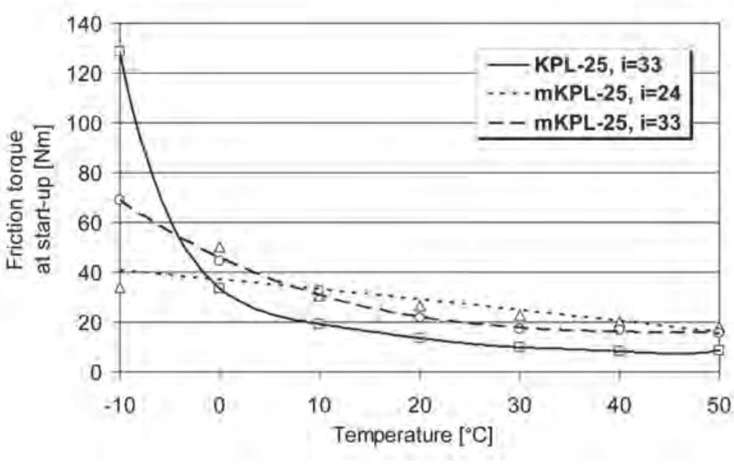

Fig. 10. The frictional torque during the start-up of the planetary gearboxes versus temperature
Rys. 10. Przebiegi momentu tarcia podczas rozruchu badanych przekładni planetarnych

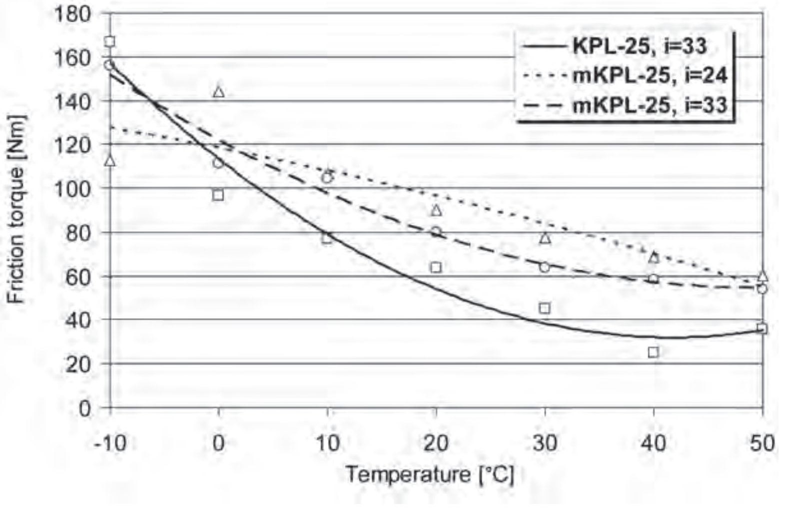

Fig. 11. The frictional torque in dynamically steady conditions versus temperature
Rys. 11. Przebiegi momentu tarcia badanych przekładni planetarnych w warunkach dynamicznie ustalonych

The results of the research on the friction torque of planetary gearboxes reflect the viscosity characteristics of lubricating oils. Synthetic oil in the mKPL gearboxes has a viscosity of 8.7 Pa·s at -10°C, and 0.16 Pa·s at a temperature of +50°C. Mineral oil in the KPL gearbox at -10°C has a viscosity of 44.0 Pa·s, and at a temperature of +50°C 0.13 Pa·s. Hence, both the start-up torque and the friction torque under dynamically steady conditions decrease as the temperature increases.

SUMMARY

At Łukasiewicz – Institute for Sustainable Technologies in Radom*, a new test rig for tribological tests was developed and manufactured. It consists of a mobile device for measurement of the start-up friction torque of transmissions, and the friction torque in dynamically steady conditions, as well as a climatic chamber to stabilize the temperature of the tested gearbox in its extreme range: from -50 to +50°C.

In the series of devices for tribological tests, developed and manufactured at the Institute, the new test rig is marked with the symbol T-34.

As part of the verification tests, three planetary gearboxes were tested. The results of the tests of the friction torque correspond to the viscosity characteristics of the lubricating oils. As the temperature increases, which causes in a decrease in the viscosity of the lubricating oils, the churning losses, both the start-up torque and the friction torque under dynamically steady conditions, decrease.

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