Experimental values of temperature distribution in a sliding bearing sleeve lubricated with non-Newtonian oils

Andrzej Miszczak
Gdynia Maritime University

ABSTRACT

This paper presents results of experimental investigations of temperature distributions on inner surface of a sleeve of transverse sliding bearing lubricated with non-Newtonian oils. The measurements were performed by means of Pt100 miniature sensors placed close to internal surface of the sleeve. To measure sleeve temperature distributions use was made of a test stand installed at Gdynia Maritime University. Delo® 1000 Marine 30 oil, SAE 15W40 basic oil, and a ferro-oil made of the SAE 15W40 basic oil were used as a lubricating medium. During measuring temperature distributions for the ferro-oil different intensity values of external magnetic field generated by electromagnets were applied.

Key words : ferro-oil, non-Newtonian oil, temperature distribution, test stand

AIM OF MEASUREMENTS AND DESCRIPTION OF TEST STAND

The main aim of the measuring of temperature distribution on the inner surface of the sleeve was to investigate influence of magnetic particles contained in oil as well as of external magnetic field intensity values on temperature distribution in slide bearing.

The experimental investigations was performed on the test stand installed at Gdynia Maritime University. The stand was built with making use of a part of T - 05 tester elaborated by Institute of Operation Technology, Radom (Fig.1.) The stand's design was made on the basis of own observations of this author and other designs presented in [1,2]. In the stand a new shaft with 100 mm diameter of journal was applied. The existing driving motor was replaced with a new one of 2.2 kW output and twice greater rotational speed than original.The SJ100-022 HFE *Hitachi* inverter was applied to made continuous control of rotational speed possible.

The stand in question makes also possible to measure relative eccentricity and friction force at given operational parameters such as : inlet oil pressure, load, rotational speed, temperature of sleeve or oil at inlet [3,4].

To measure friction force a tensometric gauge fitted with KT 1400/K/200N/2410D transducer of *Megatron*, was applied. Its measuring range for friction force reaches 200N at 0.17% non-linearity and 0.1N resolution, which gives 5mV output voltage. The gauge is supplied with 24V constant voltage and an output voltage signal is contained within 0÷10V range, equivalent to measured forces within 0÷200N range.

To determine relative eccentricity, two MDCT2/K/2410 induction extensometers of *Megatron* were added to the stand. The extensometers had built-in transducers which made it possible to read output signal in the form of standard voltage signal of 0÷10V range.

One of the extensometers was installed horizontally, the other – vertically [3,4]. They were of ±1mm range at 1μm resolution, which is equivalent to 5mV output voltage. When the measurements of the maximum sleeve translation to the left and right are made by means of the horizontal extensometer, and next the measurements of the maximum sleeve translation up and down with the use of the vertical one, then from the obtained results a value of the radial clearence of the sleeve, ε, location of the journal centre O and that of the sleeve O' , can be determined both in the hot and cold condition of the test stand. Additionally MDS10P *Technicad* contactless eddy-current sensor of journal's translation was installed to take into account journal's deflection under load.

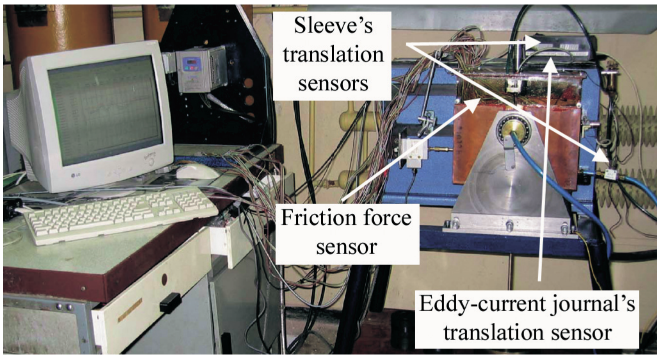

***Fig.1.** General view of the test stand for determining temperature distributions, measuring friction force and relative eccentricity in journal sliding bearing*

An additional oil tank fitted with a water cooler and 1 kW electric heater fed from an autotransformator was applied to deliver lubricating oil of appropriate temperature values to the sliding friction node. The delivered oil temperature was so controlled as to maintain it constant at oil inlet. In the lubricating system a PZ3-4/16-1-122 gear pump of 5÷6 l/min capacity and

6 bar maximum pressure, as well as a manometer and a set of control valves, were installed.

The recording of indications of the translation transducers , of friction force transducer and temperature gauge , was performed by means of *Catman* computer software and UPM100 100-channel signal recorder of *Hottinger Baldwin Messtechnik*. With the use of the recorder standard voltage and current signals can be saved, temperature values can be measured by means of thermocouples and resistance gauges, e.g. of Pt100 type, as well as indications of tensometers can be measured.

A DC-supplied electromagnet (Fig.2) was built to investigate magnetic field influence on operational parameters and temperature distribution within the gap of the sliding bearing lubricated with ferro-oil. The maximum value of the magnetic field generated by the magnet was 100 mT. The magnetic saturation of the waste ferro-oil was 50÷70 mT. Magnetic field values were measured with the use of a SMS-102 magnetic field meter fitted with a transverse sound, produced by *Asonik*.

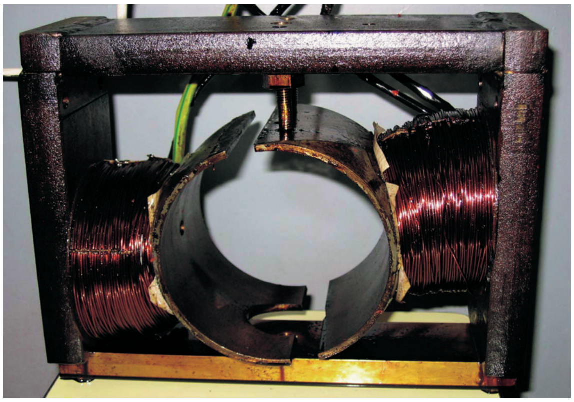

Fig. 2. *General view of the applied electromagnet*

BEARING MATERIALS

To determine temperature distribution over sleeve's inner surface the sliding sleeve made of PBM 100120120 bronze by SKF, having the following dimensions : 100 mm inner diameter, 120 mm outer diameter and 120 mm length, was selected. In the sleeve several holes to accommodate Pt100 gauges in accordance with Fig.3 were made. The gauges were placed 0.5 mm deep above the inner surface of the sliding sleeve. A way of measuring the temperature distribution was assumed the same as in the work [5]. Contact between a gauge and sleeve was improved by covering the gauge with a heat-conducting paste. The gauges were poured with an epoxy resin and connected with the UPM100 recorder by means of conductors. Fig.4 presents the arrangement of the gauges in the sleeve.

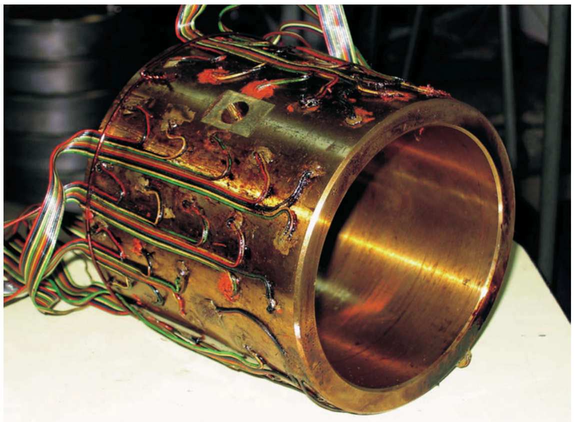

Fig. 4. *General view of the sliding sleeve for measuring temperature distribution and heat flux density*

Temperature distribution measurements were carried out for strictly determined operational parameters of the bearing and the following grades of engine oil applied as a lubricating medium :

- Delo® 1000 Marine 30 *TEXACO* ship engine oil – in fresh condition
- the same Delo® 1000 Marine 30 – in a waste condition, i.e. after 300 h continuous operation within a ship engine (of an oil-rig support & salvage tug); the oil change time recommended by ship's owner was 300 h
- Ferro-oil – made by *FerroTec* on the basis of SAE 15W40 mineral oil free of any bettering additives (i.e. basic oil). In the oil were contained Fe_3O_4 magnetic particles of 5÷15 nm in size and amount of abt. 1.5% vol., as well as a surface-active substance to prevent magnetic particles against clustering
- SAE 15W40 basic oil – delivered by Gdańsk Oil Refinery for testing

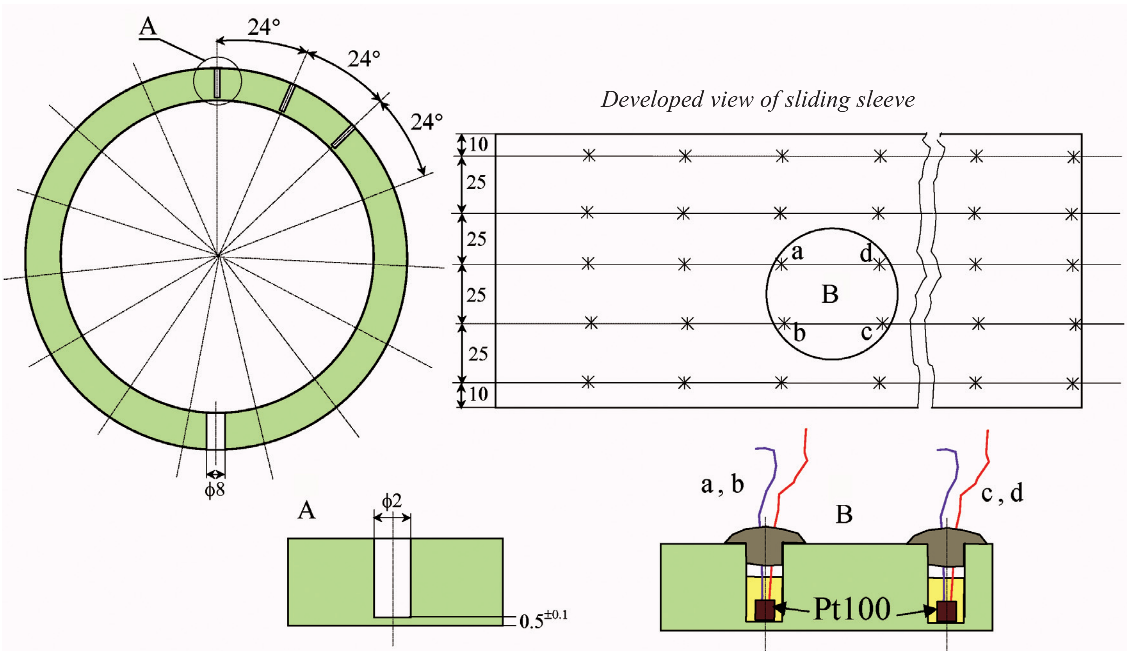

Fig. 3. *Schematic diagram of arrangement of Pt100 temperature gauges*

TEMPERATURE DISTRIBUTION MEASUREMENTS

Due to different properties of the tested oils as well as to be able to determine differences in results of measured temperatures, all the tested oils were subjected to the same selected operational parameters of the bearing. It was : its rotational speed, load, inlet pressure and temperature of lubricating oil. Tab.1. presents values of the operational parameters applied during measurements of temperature distribution.

Tab.1. *Values of operational parameters of tested bearing*

Load [N]	**Inlet oil pressure** [bar]				
	2	1.5			1
	Rotational speed [rpm]				
1034.7	2800	840	1960	2800	2800
2020	2800	840	1960	2800	2800
	Inlet oil temperature : 70°C				

The measured radial clearance ε of the tested bearing was 0.081 mm, which corresponded with the relative radial clearance ψ = 0.0016.

Before the measurements the test stand was thermally stabilized by keeping a high speed of the journal for abt.1h at simultaneous loading the sleeve with a weight. After such operation performed in each case, appropriate values of the operational parameters were set, some time was waited till stabilization of temperature indications takes place, and next the relevant temperature distribution measurements carried out.

In this paper only some results selected out of a broad testing program are presented in the form of diagrams of measured temperature distributions.

Results for Delo® 1000 Marine 30 oil in fresh condition

In Fig.5. are presented measured values of temperature distribution over the surface of PBM 100120120 sleeve for Delo® 1000 Marine 30 oil in fresh condition, under 1034.7N load, at 1.5 bar pressure and its 70°C temperature of oil at inlet, as well as for three following rotational speeds : 840 rpm (Fig.5a); 1960 rpm (Fig.5b); 2800 rpm (Fig.5c). In every figure are presented the same two temperature distributions, but shown in a different axonometric view.

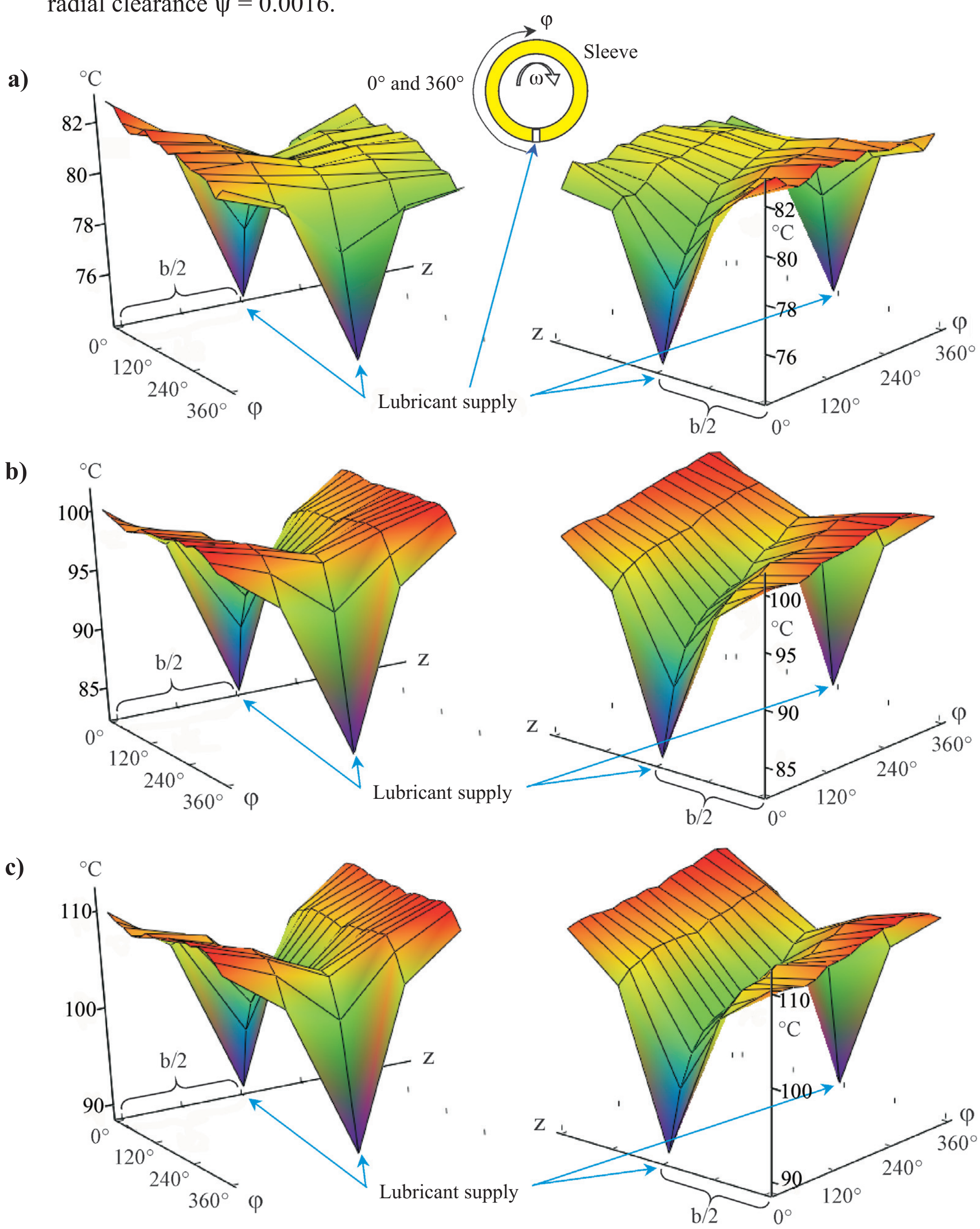

Fig. 5. *Distributions of the temperature measured on the sleeve under 1034.7 N load at 1.5 bar pressure and 70°C temperature of oil at inlet, and the following values of journal's rotational speed :* ***a)*** *840 rpm;* ***b)*** *1960 rpm;* ***c)*** *2800 rpm*

In all the diagrams, φ axes describe the direction of bearing angle, beginning from the point of some degrees behind the point of lubricating oil delivery, towards shaft's rotation. The second horizontal axis marked *z* points along bearing's length (b = 120 mm). In the middle length of the bearing a hole is made through which lubricating oil is delivered. The sleeve was not fitted with distinct oil pockets, but only with a small circular cavity abt. 0.8 mm deep, and of 10 mm diameter.

In Fig.6. is presented the influence of inlet pressure values on temperature distribution in the same oil at only one rotational speed of the journal but two values of inlet oil pressure.

Fig.6a shows the temperature distribution measured on the inner surface of the sleeve at 1 bar inlet oil pressure, under 1034.7 N load, and 70°C inlet oil temperature, and 2800 rpm rotational speed of the journal. Fig.6b shows the temperature distribution for the same values of operational parameters of the bearing as for the Fig.6a, but for the different value of inlet oil pressure, equal to 2 bar. The temperature distributions for 1.5 bar oil pressure are shown in Fig.5c.

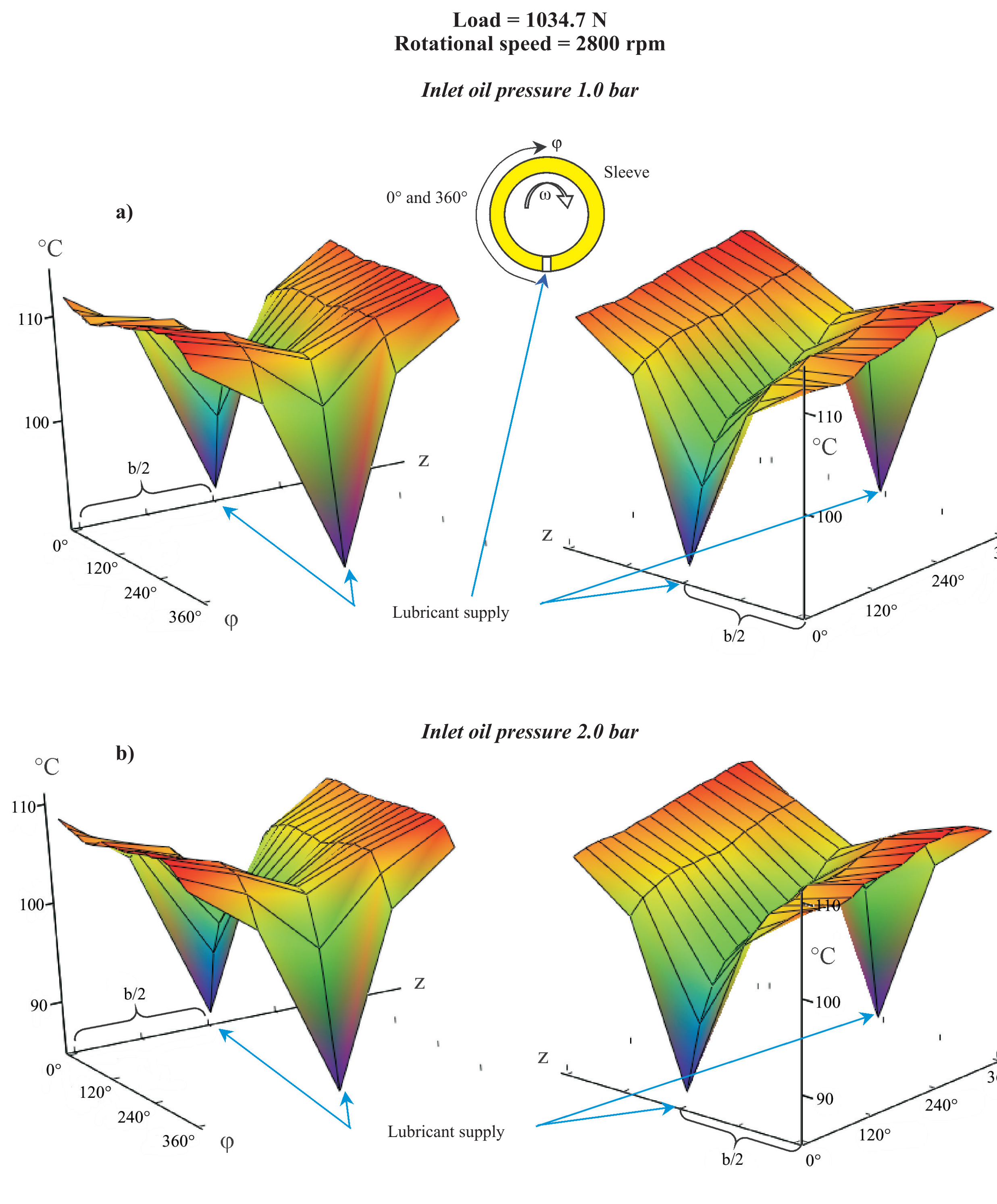

Fig. 6. Distributions of the temperature measured on the sleeve under 1034.7 N load and 2800 rpm rotational speed of the journal, for 70°C temperature of oil at inlet, and the different values of the oil pressure

Results for SAE 15W40 basic oil

During tests for the SAE 15W40 basic oil the sleeve was subjected to the same operational conditions as those for the tests of the preceding oils. The relevant results of temperature distributions are shown in Fig.7 and 8.

Load = 1034.7 N   Inlet oil pressure = 1.5 bar

Rotational speed 840 rpm

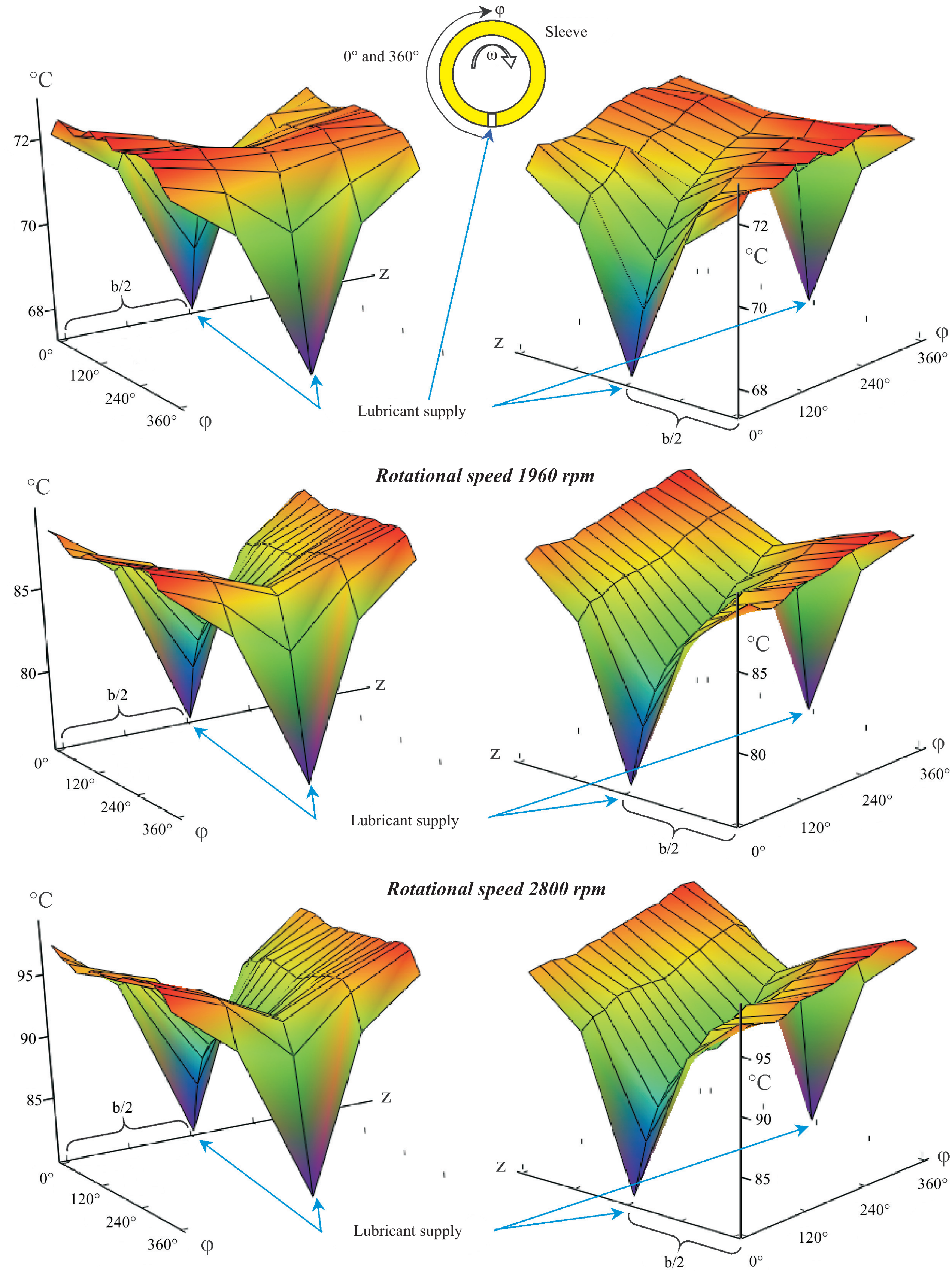

Fig. 7. *Distributions of the temperature measured on the sleeve under 1034.7 N load at 1.5 bar pressure and 70°C temperature of oil at inlet, and the different values of journal's rotational speed*

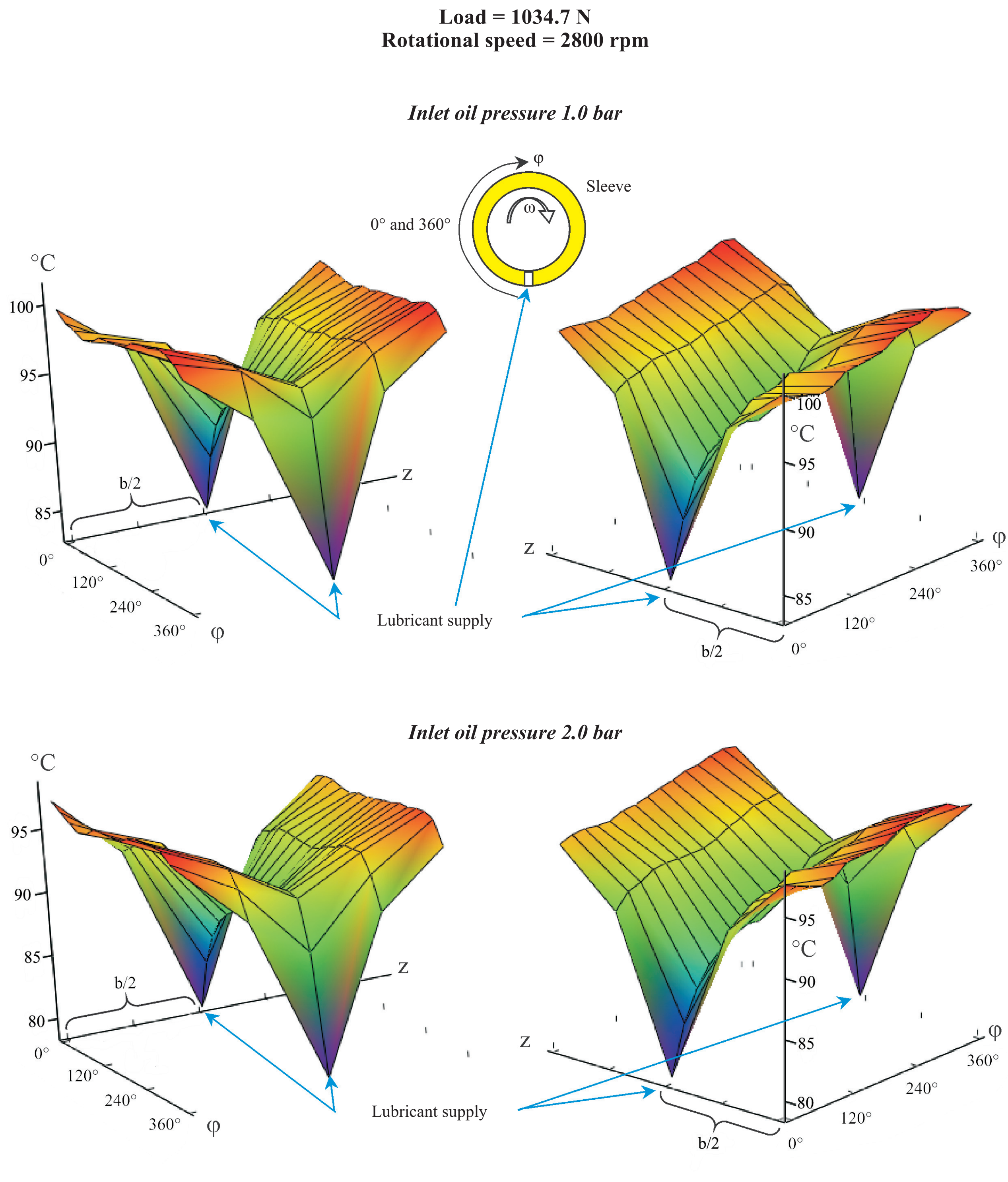

Fig. 8. Distributions of the temperature measured on the sleeve under 1034.7 N load and 2800 rpm rotational speed of the journal, for 70°C temperature of oil at inlet, and the different values of the inlet oil pressure

Results for ferro-oil

The measured temperature distributions concerned possible changes resulting from changes of journal's rotational speed and simultaneous action of magnetic field induction at a given load exerted on the bearing. Three first figures present the temperature distribution for rotational speeds of : 840 rpm; 1960 rpm; and 2800 rpm under 1034.7 N load on the sleeve and no external magnetic induction field.

The measured values presented in Fig.10 were obtained for the same speeds, inlet oil pressure and load, but for the magnetic induction field of about 30 mT intensity.

Fig.11 presents the temperature distributions also for the same rotational speeds, 1034.7 N load and 1.5 bar inlet oil pressure, but for the magnetic induction field of about 55 mT intensity.

Ferro-oil without magnetic field

Load = 1034.7 N Inlet oil pressure = 1.5 bar

Rotational speed 840 rpm

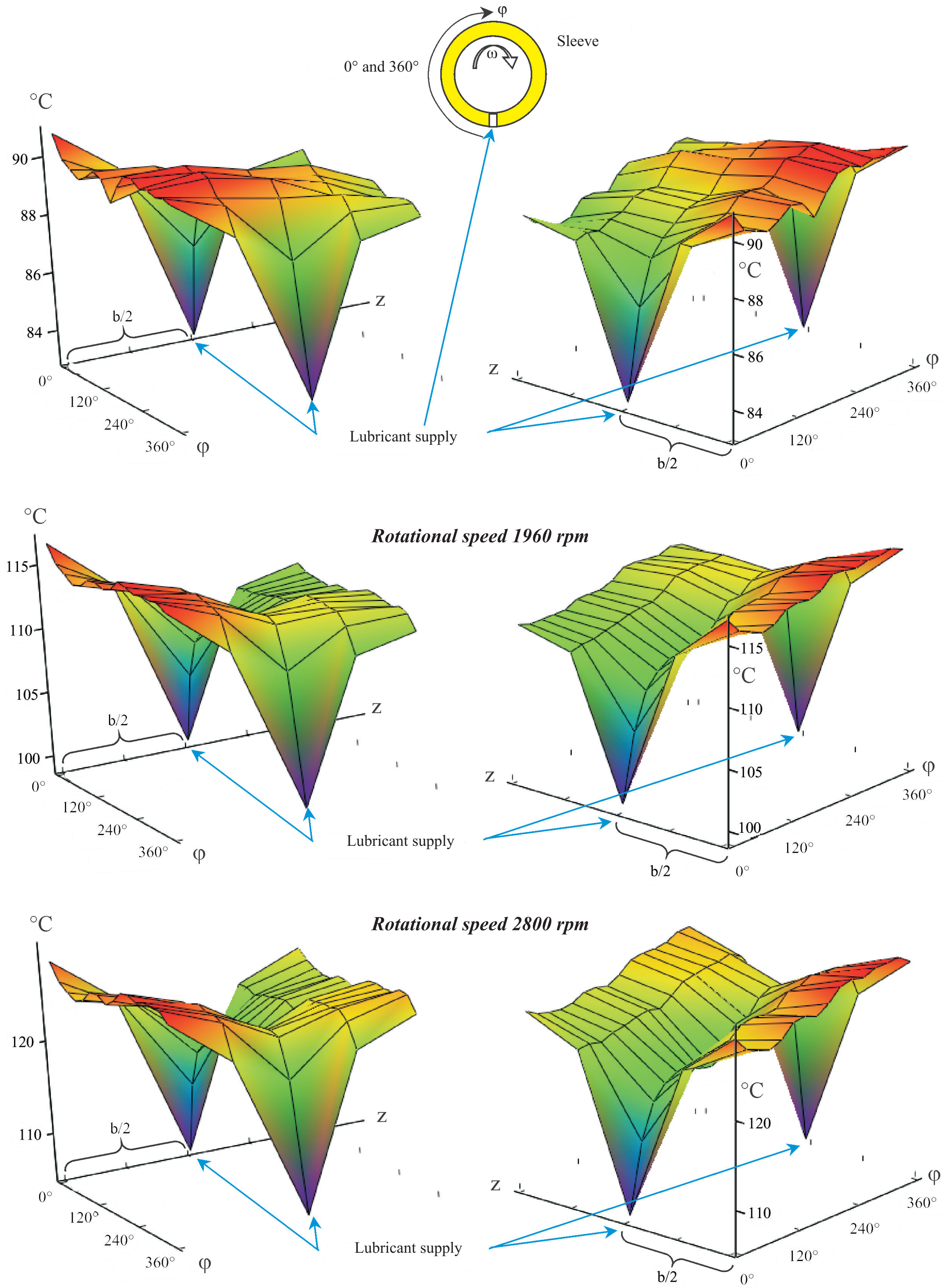

Fig. 9. *Distributions of the temperature measured on the sleeve under 1034.7 N load at 1.5 bar pressure and 70°C temperature of oil at inlet, and the different values of journal's rotational speed (no magnetic induction field)*

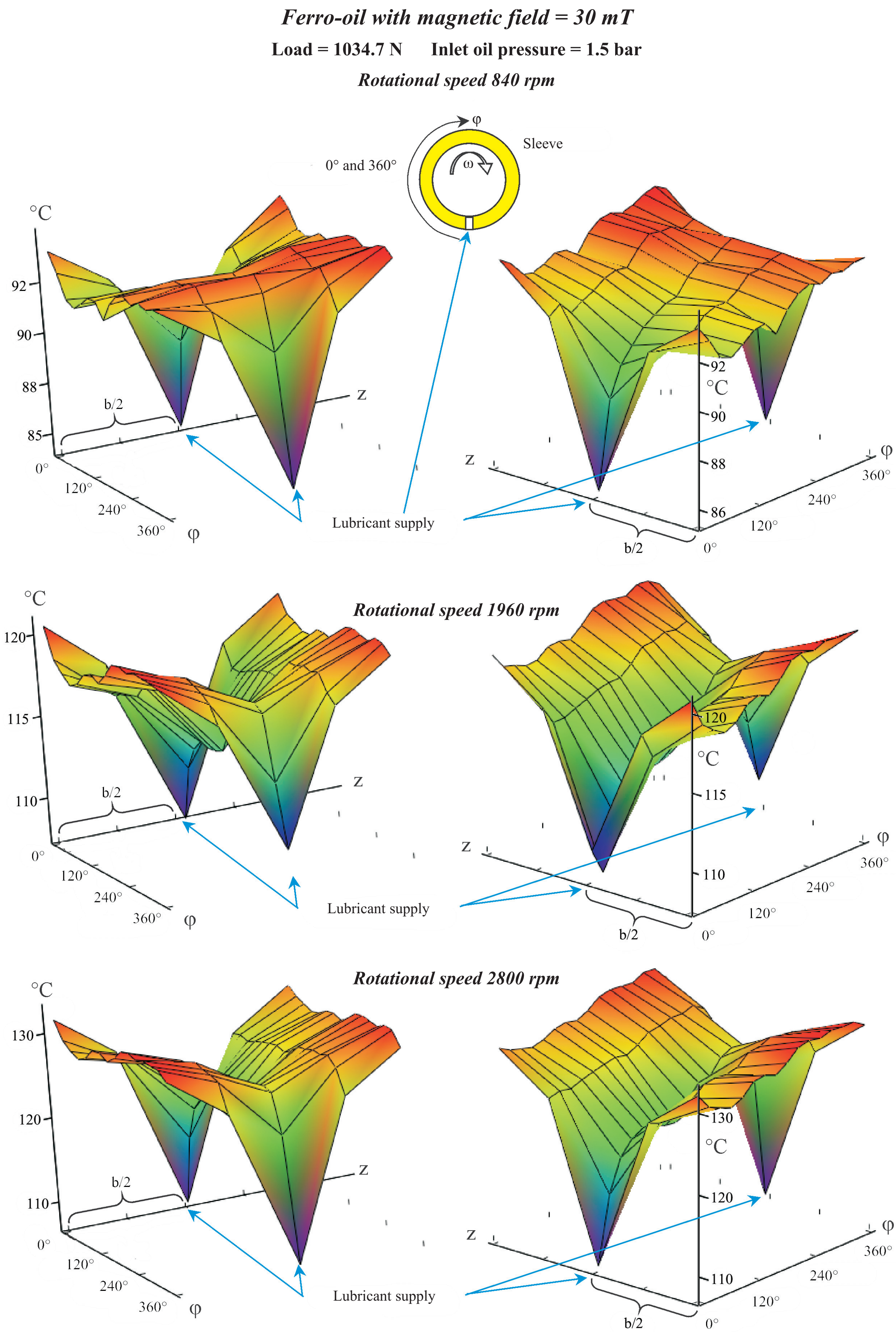

Fig. 10. Distributions of the temperature measured on the sleeve under 1034.7N load at 1.5 bar pressure and 70°C temperature of oil at inlet, and the different values of journal's rotational speed (under magnetic induction field of 30 mT)

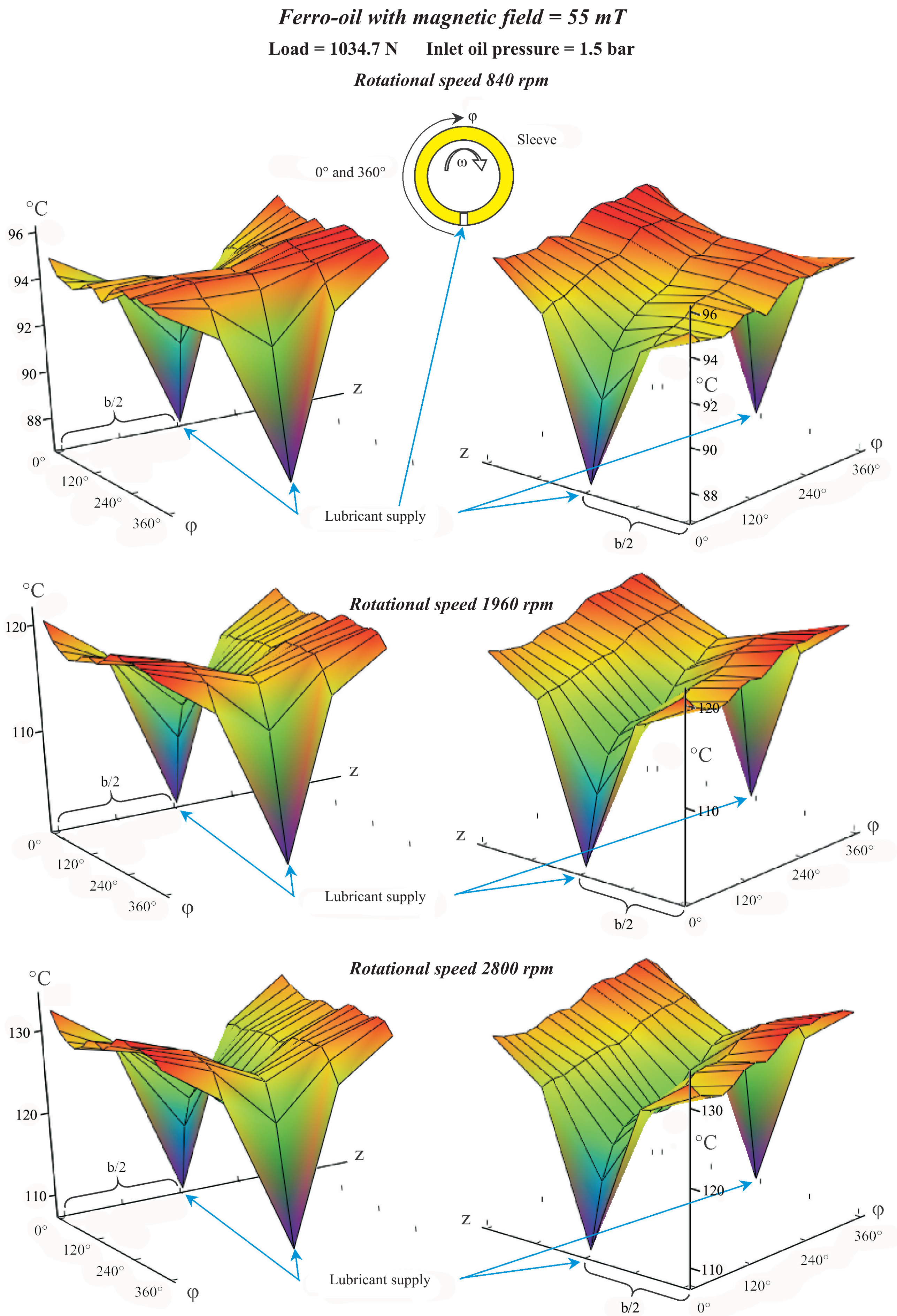

Fig. 11. Distributions of the temperature measured on the sleeve under 1034.7N load at 1.5 bar pressure and 70°C temperature of oil at inlet, and the different values of journal's rotational speed (under magnetic induction field of 55 mT)

DISCUSSION OF THE TEST RESULTS

- Apart from the above presented results of temperature measurements also the Delo®1000 Marine 30 waste oil was investigated. The obtained results differed only slightly from those for the fresh oil of the same grade. Because of publishing limitations, results of temperature measurements for the remaining oils and other operational parameters, (e.g. for 2020 N load) are not included in this paper, nevertheless they have been analyzed and discussed.
- Analyzing the values of temperature distribution one can state that the distributions for the fresh oil and waste one for the same operational parameters of the bearing differ only slightly.
- The rotational speed influence on the change of temperature distribution in the Delo®1000 Marine 30 fresh oil, at 1034.7N load, amounts to about 26% for the increase of journal's rotational speed from 840 rpm to 1960 rpm, and for the increase from 840 rpm to 2800 rpm – to about 39%.
- In the case of the waste oil at 1034.7N load on the bearing the rotational speed changes influence on the change of temperature distribution amounts to about 24% for the increase of journal's rotational speed from 840 rpm to 1960 rpm, and to about 41% for the increase from 840 rpm to 2800 rpm.
- In the case when the bearing is loaded with 2020N load, the influence of rotational speed on change of temperature distribution in the fresh Delo®1000 Marine 30 oil amounts to about 23% for the increase of journal's rotational speed from 840 rpm to 1960 rpm and to about 35% for the increase from 840 rpm to 2800 rpm.
- In the case of the Delo®1000 Marine 30 waste oil and for 2020N load exerted on the bearing the rotational speed influence on change of temperature distribution amounts to about 24% for the increase of journal's rotational speed from 840 rpm to 1960 rpm, and to about 37% for the increase from 840 rpm to 2800 rpm.
- The influence of inlet oil pressure on temperature distribution measured in the same points, both for the fresh and waste Delo®1000 Marine 30 oil at 1034.7N load on the sleeve, is slight. The inlet oil pressure increased from 1 bar to 1.5 bar lowers temperature values by about 3%, and by about 6% in the case when the oil pressure is changed from 1 bar to 2 bar. In the case when the sleeve is under 2020N load, the influence of inlet oil pressure on temperature distribution is negligibly smaller than that of inlet oil pressure on temperature distribution at a lower load.
- Analyzing the results of measured temperature distributions in the SAE 15W40 basic oil one can draw similar conclusions as those for the above discussed oil, however with the difference that the temperature values for all the just presented cases are by several percent lower than those obtained for the previously tested oil.
- Hence the influence of rotational speed on change of temperature distribution in the basic oil at 1034.7 N load amounts to about 23% for the increase of journal's rotational speed from 840 rpm to 1960 rpm, and to about 36% for the speed increase from 840 rpm to 2800 rpm.
- In the case when the bearing is under 2020 N load the rotational speed influence on change of temperature distribution in the SAE 15W40 basic oil amounts to about 20% for the increase of journal's speed from 840 rpm to 1960 rpm and about 30% for the speed increase from 840 rpm to 2800 rpm.
- The influence of inlet oil pressure on temperature distribution in the basic oil is also low. For 1034.7N load applied on the sleeve, and the same measurement points, it amounts to about 3.5% for the inlet oil pressure increased from 1 bar to 1.5 bar, and to 6.5% – when the pressure is changed from 1 bar to 2 bar.
- The influence of inlet oil pressure on temperature distribution in SAE 15W40 basic oil under 2020 N load exerted on the sleeve, measured in the same measurement points, is equal to about 2% for the inlet oil pressure increased from 1 bar to 1.5 bar, and 2.6% for the oil pressure increased from 1 bar to 2 bar, respectively.
- Analyzing the measured temperature distributions for ferro-oil, presented in Fig. 9÷11, one can draw similar conclusions as those for the previously considered oils, with the difference that the temperature values for all the cases actually considered are by a dozen or so percent greater than the temperature values obtained for the previously tested oils.
- When comparing temperatures of other oils with basic oil temperature it can be observed that the difference is even as great as 35%. Reminding that the ferro-oil was made of the basic oil, one can attribute its increased viscosity to the introduction of magnetic particles and the application of magnetic induction field.
- The influence of journal's rotational speed changes on temperature distribution changes during lubricating the bearing with the ferro-oil was tested for 1034.7N load exerted on the sleeve. When the journal's rotational speed was increased from 840 rpm to 1960 rpm the temperature increased by about 29% (at 0mT magnetic field intensity during measurements), 29% (at 30mT), 27% (at 55mT), and for the speed increase from 840 rpm to 2800 rpm the temperature increased by 43% (at 0mT), 42% (at 30mT), 40% (at 55mT) respectively.
- In the case when 2020N load was applied to the bearing the rotational speed influence on change of temperature distribution in the ferro-oil amounts to about 29% (at 0mT); 24% (at 30mT); 23% (at 55mT) as a result of the increase of journal's rotational speed from 840 rpm to 1960 rpm, and about 42% (at 0mT); 36% (at 30mT); 35% (at 55mT) as a result of the increase of journal's rotational speed from 840 rpm to 2800 rpm.
- The influence of inlet oil pressure on measured temperature distribution is, like for other oils, low and contained within the range of 2%÷3% as a result of the change of inlet oil pressure within the range of 1÷2 bar.

CONCLUSIONS

- Considering the obtained test results both presented and not presented in this paper (due to a huge amount of them) one can draw the following conclusions :
  - The difference between the values of temperature in the tested waste oil, distributed on the inner surface of the sliding bearing sleeve in question and those in the fresh oil of the same grade in the same lubricating conditions, is small. The temperature increase by a few percent for the waste oil can be justified by its increased viscosity. The greater viscosity makes values of friction force increasing and thus more heat is emitted. At the same amount of the flowing oil and a greater amount of heat generated within oil film its temperature must be higher than that of an oil of lower viscosity.

- Great differences can be observed between the distributions of temperature measured on the inner surface of the sliding bearing sleeve, for the ferro-oil and basic oil as well as those for the remaining tested oils, which can be justified by a difference in viscosity of the oils in question resulting from the presence of magnetic particles in the ferro-oil.
- By comparing the temperature distributions obtained for the basic oil with those for the ferro-oil affected by the magnetic induction field, at the load of about 1034.7N and the journal's rotational speed of 2800 rpm, the temperature increase by about 30÷40% can be stated on the inner surface of the sliding bearing sleeve.
- As the presented figures show, the rotational speed increase makes values of the sleeve's temperature increasing , as well as the difference between the highest and lowest value of sleeve's temperature greater. The high temperature drops appearing in the central part of the diagram result from the delivering of lubricating oil at 70°C temperature, to that point.
- The distinct temperature drop resulting from the increased load on the sliding bearing can be observed. The phenomenon could result from that at a high load the maximum lubricating gap increases, thus a greater amount of lubricating oil could flow through the gap at an assumed constant inlet oil pressure than that flowing through a narrower gap at a lower load.

❍ When analyzing the temperature distributions on the inner surface of the sliding bearing sleeve, are worth of noting the very great changes of temperature along the bearing length (a kind of „funnel" in the part of diagram corresponding with the central part of the bearing). The changes resulted from the way in which the oil was delivered : a flow of much cooler lubricating oil was point-wise delivered out of the lower part of the sliding sleeve to the lubricating gap in its greatest height. In this place it intensively cooled the journal and sleeve, due to which the temperature in the middle-length of the bearing from the side of oil delivery reached the lowest values.

❍ When analyzing the measured values of temperature distribution it can be observed that their circumferential changes reach a dozen or so degree centigrades depending on a journal rotational speed and load applied to sleeve.

❍ It should be remembered that the tested oils at the same radial clearance, load, rotational speed, inlet oil pressure and temperature could have various relative eccentricities resulting from different values of oil viscosity, which led to different heights of lubricating gap and different values of lubricant flow rate. The phenomenon also affected temperature distributions.

BIBLIOGRAPHY

1. Hebda M., Wachal A.: *Tribology* (in Polish). WNT (Scientific-Technical Publishing House). 1980
2. Korewa W., Zygmunt K.: *Essentials of machine construction* (in Polish) Part.I and II. WNT. Warszawa, 1971
3. Miszczak A., Wierzcholski K.: *Alterations introduced to T-05 test stand for measuring friction force in sliding bearing* (in Polish). 24th Autumn School on Tribology, Section of Exploitation of Machine, Mech. Eng. Committee, Polish Academy of Sciences. Krynica, 2000, Problemy Eksploatacji (Problems of Operation) No. 3/2000
4. Wierzcholski K., Miszczak A.: *Conversion of T-05 tester into a test stand for determining oil viscosity* (in Polish). Silesian University of Technology. Zeszyty Naukowe (Scientific Bulletins), No. 14/2000
5. Breczko T.: *Some aspects of calculation of transverse sliding bearings* (in Polish). Rozprawy Inżynierskie (Engineering Discourses), Vol. 23, No. 3/1975

CONTACT WITH THE AUTHOR

Andrzej Miszczak, D.Sc., M.E.
Gdynia Maritime University,
Faculty of Marine Engineering
Morska 81-87
81-225 Gdynia, POLAND
e-mail : miszczak@am.gdynia.pl

Miscellanea

TOP KORAB in 2004

Apart from its current activity, The Polish Society of Naval Architects and Marine Engineers, TOP KORAB every year arranges topical meetings dealing with shipbuilding and maritime economy.

In the year 2004, 12 such meetings had place : 9 in Gdańsk and 3 in Szczecin.

In Gdańsk the following topics were discussed :

- *New ship designs offerred by Gdynia Shipyard Co*
- *Building of replicas of ancient ships and boats in Europe*
- *Beginnings of ship model tests in Poland*
- *Diesel engines of MAN Co*
- *Beginning and development of Polish Register of Shipping*
- *Shipbuilding Secondary School in Warsaw in the years 1936 ÷ 1945*
- *Activity of Central Ship Design Office No.2*
- *Petrobaltic Co − a company exploiting hydrocarbon resources in Polish zone of Baltic Sea*
- *Flashback to 1958 ÷ 1980 : a balance of my professional career in Gdańsk Shipyard* (by K. Gniech).

And, the visiting trip to the Central Maritime Museum's branch house in Kąty Rybackie on the Vistula Sand Reef, was also organized.

The themes of the meetings in Szczecin were the following :

- *Reasons for downfall of Szczecin Shipyard Porta Holding Co*
- *LEADERSHIP 2015 − the plan of modernization of European shipbuilding and ship repair industry*
- *Selected problems of DNV activity aimed at improving safety at sea.*

Besides, the visit to GRYFIA Ship Repair Yard was arranged where the participants took part in a ship launching ceremony.