TRIBOLOGICAL SYSTEMS OF SURFACES WITH FRICTIONAL RESISTANCE REDUCTION

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Abstract

In this paper are assumed micro-ridges and micro-grooves on t he journal and bearing sleeve surfaces. Friction on the boundary layer of the body moving in the oil at high Reynolds numbers may be decreased due to su ch a sculpturing of the surface. The grooved scale of the shark skin is an example of such tribological systems. There size ranges of the grooves are from 200μm to 400μm. The surface of the each scale contains parallel groove between so-called ribbed directed almost parallel to the longitudinal body axis . An explanation of the shark skin effect has been proposed recently for the micro-bearing surfaces shapes execution. In the boundary layer, not only longitudinal micro-turbulence but also cross-directed micro-turbulence occurs. The longitudinal grooves of the shark and bearing surface prevent the appearance of the cross-directed micro-turbulences.

Forces of the streaming oil in bearing or micro-bearing gap act on the bearing surface in two different ways. On one side, the oil generates the pressure directed normally to the surface of the journal surface and is responsible for inertia forces. On the other side, friction or shearing force acts tangentially to the bearing surface. The resulting force depends on the geometry of the body, its relative dimensions to the oil flow and on such characteristics of the oil as its density, viscosity and velocity.

Keywords: *nano-ridges, groove geometry, reduced friction, micro-bearing, shark skin*

1. Introduction

The purpose of this study is to clarify the tribological mechanisms behind the dropping friction between surfaces that work together or between a liquid and its surface based on its surface texture. The geometry of nanometre grooves and ribs on surfaces that work together is essential to explaining the phenomenon of friction decreasing despite high revolutions [3, 4, 6, 7]. Such surfaces have been shaped by nature through evolution and are now considered in technology. This study gives examples of these phenomena in nature and their application in tribology [7].

2. Comments on friction

The swimming in fish, whales, sharks, dolphins takes place based on the shape of the body, skin and organs striking against the liquid that is fins. The stream of liquid in the microscopic scale works on a swimming body in two directions. Liquid in motion generates pressure acting perpendicular to the body. In addition, friction forces and shear forces develop, tangentially to the surface of the body. We are dealing with two Reynolds numbers, namely:

$$\mathrm{Re}_1 = \frac{UL\rho}{\eta}, \quad \mathrm{Re}_2 = \frac{U\varepsilon\rho}{\eta}, \tag{1}$$

where:
U - linear flow velocity,
L - body length,
ε - thickness of the boundary layer of liquid around the fish body,
ρ - density of the liquid,
η - dynamic viscosity of the liquid.

The boundary layer of the fluid is very thin at about 700 micrometers. Outside this boundary layer, the liquid can be regarded as in viscid. The increase in thickness of the ε boundary layer causes an increase in the second Reynolds number. In the boundary layer, liquid can have laminar or turbulent flow. In laminar flow, particles flow parallel to the surface of the body. In turbulent flow, turbulence of particles occurs in every location and in all sorts of directions, which signifies chaos. Turbulent flow results in higher friction compared to the frictional resistance arising during laminar flow. Laminar flow turns into turbulent flow at some critical values of the Reynolds numbers. We have two values of critical Reynolds numbers relating to the first and second form of the number, namely [7]:

$$\mathrm{Re}_{kr1} = 3.2 \cdot 10^5, \quad \mathrm{Re}_{kr2} = \mathrm{Re}_{kr1}\sqrt{\frac{\varepsilon}{L}} \approx 41. \tag{2}$$

Whales swim at very high values of the first Reynolds number of up to 10^8. We then have low values of dynamic viscosity and high velocities. Plankton in water flows at very low Reynolds number values, as the forces of dynamic viscosity have a significant advantage over the forces of density. The second value of the Reynolds number Re_2 is important in the formation of frictional resistance in the flow. Friction forces are also defined using two following models:

$$F_{R1} = \frac{\eta US}{\varepsilon}, \quad F_{R2} = pS, \tag{3}$$

where:
S - surface flown around.

The first relation function depends additionally on speed U and the other, on pressure p

3. Effects of reducing flow resistance

Dolphin skin is relatively smooth and soft. A cross section of the skin layers and an analogical model of the skin are shown in Fig. 1.

Adhesive mucus secreted on the surface of the body flown around, i.e. on the outer surface of the body, shell, rough skin, affects the flow velocity gradient, type of movement and thickness of the boundary layer around the body [6]. A long chain of polymers contained in the mucus reduces the pressure gradient and reduces friction. This effect is caused by the particles' route of movement in the flow direction. The mucus is soluble in water but in places where microturbulence is created, mucus becomes insoluble which results in the attenuation of waves and turbulence. The phenomena described cause a reduction in turbulence and a change in value of the resisting forces. For this reason, a dolphin can reach extremely high speeds within seconds.

Research by W. Fahrenbach, D. Knudson [2] shows that the epidermal subcutaneous layer, for example in fish, affects the reduction or increase in friction forces while skin are flown around while swimming. Experiments by Nachtigall and Scherge [5, 6] confirm that dolphin skin reduces friction down to 60% by shifting the critical values of the Reynolds number to larger values, thus delaying the transition to flow from laminar to turbulent. This fact is caused by the

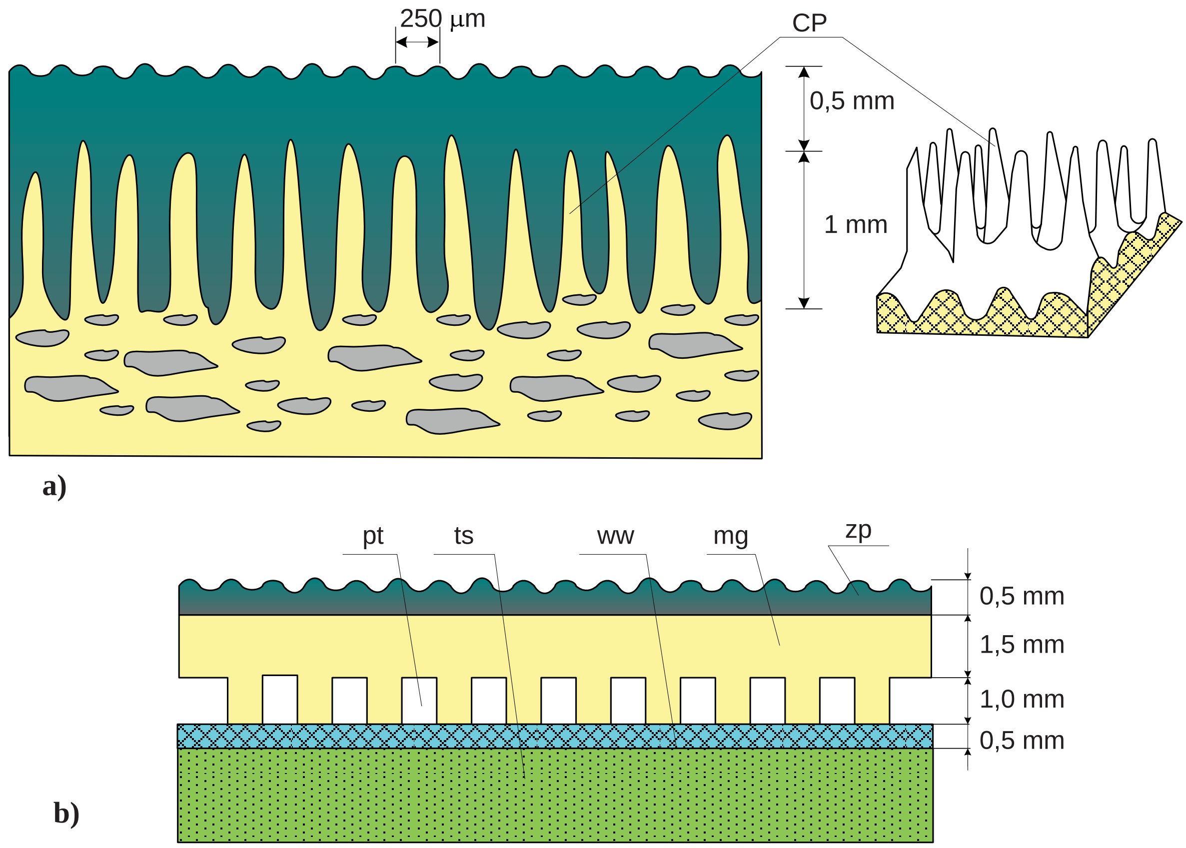

Fig. 1. Geometry decreasing friction in fluid at the large Reynolds number: a) schematic of dolphin skin; b) artificial coverage designed analogous to the dolphin skin; CP -corium papillae, zp - covering layer, mg - soft rubber layer, pt - damping fluid, ww - inner layer, ts - hard underlying layer of the body

damping of turbulent waves initiated by the outer surface of the skin. On the surface of the skin, grooves and ribs can be seen. Observations made using an atomic force microscope (AFM) made it possible to see the grooves and microribs on the shark skin surface as shown in Fig. 2. Arrowheads in Fig. 2 indicate the direction of movement of particles while the shark is swimming. The boundary layer around the body of a shark moving in water at high Reynolds numbers, the friction forces are reduced through the sculpture of the skin surface, which shows grooves and microribs. The height of the ribs can reach as much as 200 to 500 micrometers [5, 6].

Figure 3 shows the effect of the shapes of microribs and their mutual distance on the surface of the skin on the reduction of frictional resistance generated during movement.

Experimental studies [5, 6] show that frictional resistance is reduced when the distance between the peaks of the ribs is less than half the length of the lateral wave of liquid turbulence. The sharp tips of the rib peaks prevent transverse flow of the liquid in the boundary layer, because they alter the movement of fluid particles from vertical to axial direction. The frictional resistance along the thickness of the boundary layer are much higher than the frictional resistance during movement of liquid particles in a direction parallel to the surface during the flow. For example, friction resistance in the boundary layer deposited on a micro-ribbed surface is reduced from 5 to 10% compared to frictional resistance arising when smooth skin is flown around for Reynolds numbers of up to 1.5×10^{6} [5, 6]. Longitudinal grooves on the shark scales prevent the initiation of micro-turbulent transverse waves in transition from laminar to turbulent flow. Also, aerodynamic force of birds and fast-flying insect's increases by an appropriately sculpted body surface roughness or micro-ribs shaped with nano-hairs on the skin surface. The properties of skin presented have been applied in sliding micro-bearings with a diameter of 3 mm in order to reduce friction [7]. Micro-bearings used in HDD are shown in Fig. 4.

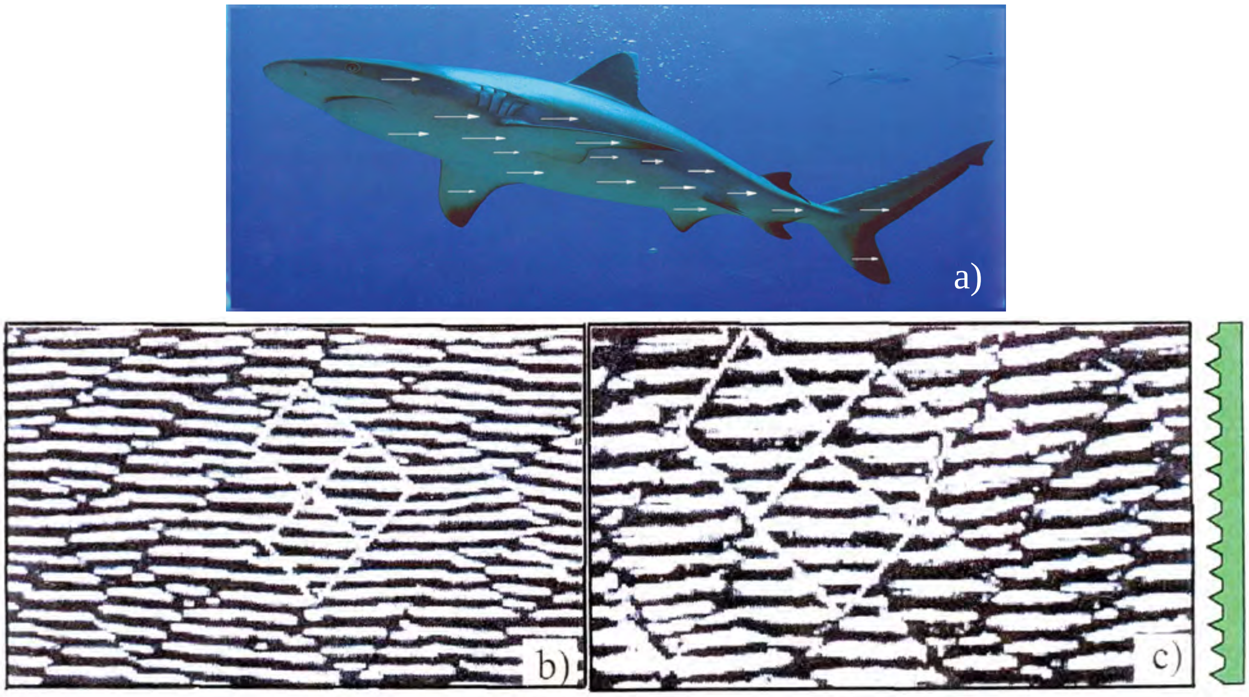

Fig. 2. Shark skin surface after Nachtigall and Scherge [5, 6]; a) directionality of the ribbed groove pattern in the shark, b), c) fragments of the scale surface of two sharks with visible cuts and grooves on the skin surface

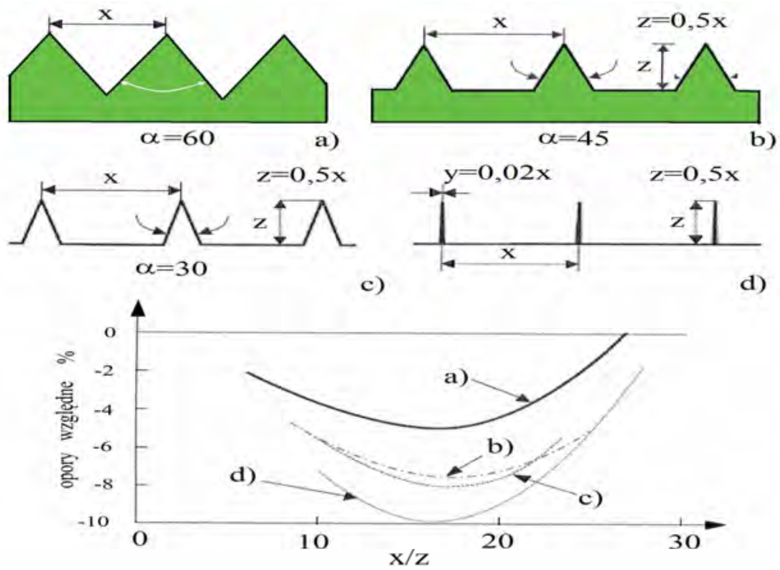

Fig. 3. Shark skin effects after Scherge and Nachtigall [5, 6] in the form of reduced relative frictional resistance values caused by the grooves and ribs about 200 micrometer height for dimensionless values ratio of the distance between ribs and ribs height taking into account various shapes of the ribs a)÷d)

By moving between the nano-fins, molecules of liquid contained in the nano-grooves reduce the frictional force due to loosening between molecules shown in the second row as shown in Fig. 5. The larger the spacing between the nano-fins, the greater the loosening and thus the greater the reduction in friction resistance. This effect is shown in Fig. 5. This description confirms the experimental results as far as reduction of friction is concerned, as shown in Fig. 3.

The aerodynamic lift of the micro-bearing is also increased by turbulent vortices around the nano-fins inside the nano-grooves as shown in Fig. 6. Arrowheads in Fig. 6 indicate the direction of motion of fluid particles. Anti-vortices increase when the contours of the nano-fins get steeper. Then there is a greater reduction in friction, as confirmed in the experimental results shown in Fig. 3

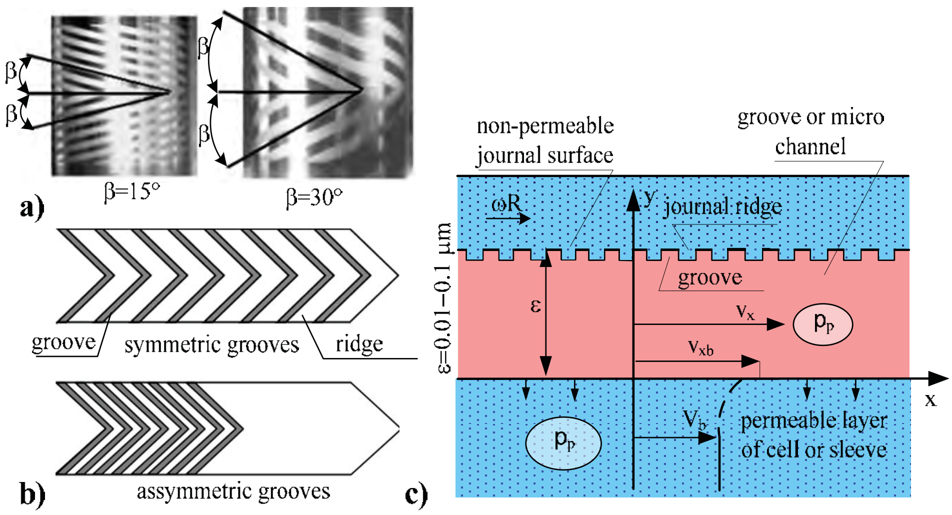

Fig. 4. The micro-bearing gap or channel: a) various groove angles in journal, b) symmetric and asymmetric groove, c) gap restricted by the permeable surface of body cells and the grooves in the micro-journal

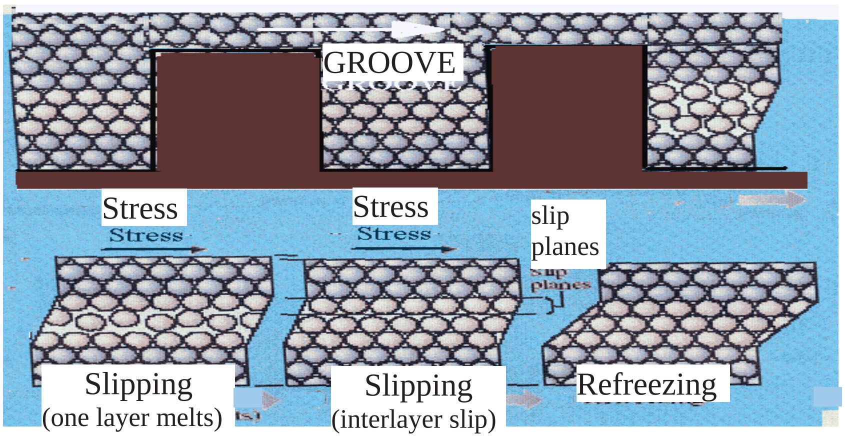

Fig. 5. Documentation of the frictional resistance reduction during the fluid particle motion between nano or micro-ribs [9]

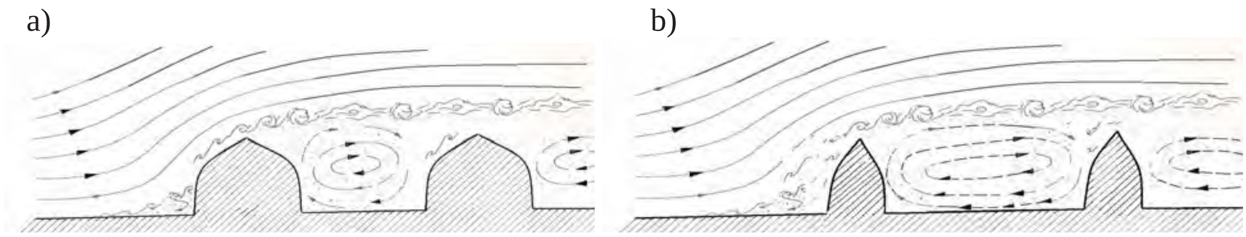

Fig. 6. Whirls and anti-whirl: a), b) whirl increases for more slim ribs, b) whirls and anti-w hirls between two ribs and its influence on the frictional resistance decreases [9]

An example of friction reduction can be the humpback whale. The humpback is a whale that is a marine mammal with fin-like forelimbs and fading hind limbs. The humpback's organ of motion is the horizontal tail fin. A humpback whale can reaches 18 in length and from 30 to 50 tons in weight. It migrates from the Arctic seas to the temperate zone. At the dewlap, the Humpback has longitudinal furrows Fig. 7.

An aircraft constructor can learn quite a lot from a humpback. The scientists' interest was aroused by how an animal with a rather rigid body can turn tight circles in the water. They found that the front edge of the fins is not smooth, as is the case with aircraft, but covered with bumps. With the water flowing around the fin, gaining speed and moving in an orderly manner. Specialist John Lang believes that "soon, every jet plane will have wings with bumps similar to those of the humpback whales."

Fig. 7. Longitudinal furrows and grooves on the Humpback whale dewlap

4. Conclusions

The justification for reduced friction based on hydrodynamics is due to the following reasons:
1. loosening of molecules arranged in the fluid during movement between the nano-fins,
2. increase in anti-vortex as nano-fin geometry changes during the flow of liquid between the nano-fins.

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