J. Mater. Eng. (1991) 13:47–53

Running-in: Art or Engineering?[1]

Peter J. Blau

Abstract. Running-in is an initial surface and subsurface conditioning process that often occurs when sliding or rolling contact is established between two solid bodies. This article first addresses and defines the nature of running-in as it relates to steady-state sliding conditions. Running in procedures are not always given the type of systematic analysis that goes into other forms of friction and wear testing, but are often developed by trial and error. Studies of running-in are relatively rare in the literature of tribology, and they often appear with only passing mention. The concept of a running-in (break-in) map is explored. Examples of the analysis of friction traces show how they can be used systematically to study the running-in process. Running-in is found to be a property not only of the materials in contact, but also of the system in which they reside.

Introduction

Although the term running-in[2] is used often in the field of tribology, it means different things to different people. To some, it refers to an operational procedure used to condition surfaces for optimal friction or wear performance. To others, it refers to the changes in friction and/or wear which occur before a tribosystem reaches steady state after start-up. Therefore, before defining running-in, it is necessary to define steady state. The following definition is offered [1]:

> **steady state,** *n.*—in tribology, that condition of a given tribosystem wherein the average kinetic friction coefficient, wear rate, and/or other specified parameters have reached and maintained a relatively constant level. Note: Other parameters which could be used to define the steady state include temperature, concentration of debris particles in a lubricant, and surface roughness.

While steady state in some tribosystems is not truly "steady" (i.e., momentary fluctuations in friction and wear might occur), the system tends toward a nominal friction coefficient and a linear rate of wear. Therefore, running-in is defined as follows:

> **running-in,** *n.*—in tribology, those processes which occur prior to steady state when two or more solid surfaces are brought together under load and moved relative to one another. Note: These processes are usually accompanied by changes in nominal friction coefficient and/or rate of wear.

Run in (no hyphen) is the verb form of running-in which refers to the operating parameters initially imposed on a tribosystem for the purpose of surface preconditioning: one runs in a surface.

Historically, running-in is usually associated with changes in the microgeometry of the mating surfaces so that they conform better with one another. In the words of the classic paper by Abbott and Firestone [2]:

> When two newly machined surfaces are placed together, they touch only on the peaks of the highest irregularities, and the actual contact area is very small. If the surfaces are "run-in" under load, or otherwise fitted, the projecting irregularities are gradually removed and the actual area of contact is increased. At first the wear is quite rapid, but it decreases as the contact area increases.

---

[1] Research sponsored by the Office of Energy Utilization Research, Energy Conversion and Utilization Technologies (ECUT) Program, U.S. Department of Energy under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

[2] "Running-in" is the noun or adjective form (e.g., using a running-in lubricant), and "running in" (no hyphen) is the verb form (e.g., running in a bearing) of the term.

The author is with the Metals and Ceramics Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6063, USA.

Numerous studies of the changes in surface roughness as wear progresses have followed this work.

Running-in of bearings is also associated with the concept of the "shakedown limit" introduced by Johnson [3]. Shakedown occurs when contact induced work hardening (in metals) and surface compressive stress build-up prevents further plastic deformation of the surface after a period of contact. The maximum load for which this sequence can occur is called the shakedown limit. In the case of ceramics, application of the traditional shakedown arguments is questionable, and more research is needed to determine whether phenomena comparable to work-hardening in metals play a significant role in the running-in of hard ceramic surfaces. Generally, ceramics are used in such a way that very mild wear occurs, and the grosser changes associated with the running in of metals are not observed.

Running-in serves an important function in lubrication. This is easily understood in the context of the film thickness parameter and its role in lubrication theory. The film thickness parameter (Λ) is defined in terms of the mean surface separation distance (h) and the root mean square (RMS) roughnesses of the opposing surfaces (R_{a1}, R_{a2}, respectively) [4]:

$$\Lambda = (h/R^*), \text{ where } R^* = [(R_{a1})^2 + (R_{a2})^2]^{0.5} \quad [1]$$

When $\Lambda < 3$, partial film lubrication occurs, and when $\Lambda > 3$, full film lubrication occurs. Therefore, as R_{a1} and/or R_{a2} become smaller during running-in, the lubrication regime becomes more effective. However, if the surface becomes too smooth, it can become difficult to supply further lubricant to the contact zone via channels in the surface roughness, and some lubricants with lower load bearing capacity can be squeezed out of the interface. Therefore, achieving an optimal run-in surface condition is desirable.

Running-in lubricant formulations for metal tribosystems have been developed. In some cases, the higher acidity of the lubricant may aid in the surface conforming process by helping to dissolve the sharpest asperities on the as-machined surface. In other cases, fine abrasives may be added to the lubricant to help polish the mating surfaces. In using running-in oils, it is important that they not reside in the machine too long and that they are replaced by normal lubricants when their job has been completed. The 1987 edition of the *Thomas Register* [5] lists 25 manufacturers under the heading "Lubricants: Assembly and Running-in."

Changes in surface roughness, lubrication regime, and shakedown (in metals) are only some of the aspects of running-in. On the level of microstructure, running-in can produce near-surface, highly deformed surface layers, dislocation defect structures, deformation twins, and adiabatic shear bands depending on the materials and contact conditions. Running-in can also fatigue the contact surface and initiate the damage precursors which lead eventually to microcrack formation and larger debris particle generation.

Surface chemical conditions can also be changed during the running-in process. The kinetics of reaction between the rubbing surfaces and the surrounding environment may be changed during running-in [6], and frictional heating can also facilitate reactions with the environment. In summary, running-in is a complex process involving geometric changes, elastic and plastic deformation, microstructural changes, thermal changes, and chemical changes on and below the contacting surfaces, all occurring simultaneously.

Running-in: The Art

Not all running-in procedures have been developed by careful, systematic studies. Sometimes, the operator of a machine has discovered a good way to run in new bearing components after maintenance-required replacement. A new operator may need to relearn the unwritten techniques of his predecessor. Undoubtedly, many undocumented running-in methods have been developed by trial and error, but the effectiveness and reproducibility of these trial-and-error techniques may vary from one application to another.

Outward signs that a machine or component has run in have been used in practice. One of these is the temperature of the bearing housing. Frictional heating of fresh, nonconforming surfaces may cause an initial temperature rise in the bearing. As running-in progresses, the temperature may drop to a level characteristic of the usual steady state operation of the machine. Other outward signs of the changes in the tribosystem may involve the characteristics of the noise made by the machine or the level of vibration. Sometimes, the content of wear debris in the lubricant can be sampled to determine whether the higher wear rates associated with running-in have subsided.

Different running-in procedures may be required when either one or both mating components in a machine are replaced, because the starting contact conditions are different. Experiments in which reused steel rings were slid unlubricated against newly polished aluminum bronze surfaces in a block-on-rotating ring test showed that the running-in period was reduced with used rings [7]. Furthermore, the ratio of the time required to reach a steady friction coefficient versus that to reach a steady rate of wear decreased with the number of prior ring uses (see Table 1). A "break-in (i.e., running-in) map" showing the relationship between the time to reach constant friction conditions and the time to reach a constant rate of wear for different materials is shown in Figure 1.

Understanding how and when to run in certain types of bearings and machinery sometimes takes on the characteristics of an art, based to a large extent on practical experience and the development of "tricks of the trade."

Running-in: Engineering

A considerable body of the engineering work on running-in seems to reside more in manufacturers' records than in the published literature. Such information may give one machine or component producer a competitive advantage over another, so it is reasonable to assume that running-in information is protected from public disclosure. Certain bearing designs contain features which promote running-in and seating.

Table 1. Changes in a Tribosystem Associated with Running-in

Change	Possible Cause
Surface roughness	Asperity deformation and fracture; microconformation may take place; a steady state roughness value may be achieved
Friction may increase or decrease	Smoothing/roughening of surface changes the lubrication regime; also, surface films, transfer, debris, temperature changes can affect friction
Temperature increases	Frictional heating
Surface work hardening (in metals)	Shear stresses deform and work harden the near-surface regions ("shakedown" may occur)
Oxide films form	Frictional heating and/or tribodeformation changes the chemical reactivity of the surface
Rate of wear	Change in wear processes as the system tends toward a steady state condition
Subsurface defect structure	Deformation produces microstructural defects whose configuration and depth depend on the stress conditions and the type of material involved

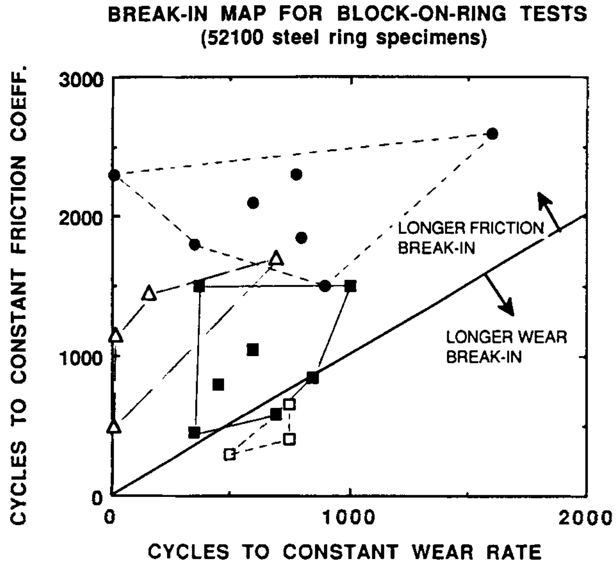

Fig. 1. Relationship between the time to ready steady state in friction and the time to reach steady state in wear for various materials sliding on 52100 steel rings. After [1]. □, Tool steel; ●, 1015 steel, △, CuAl alloy; ■, Dual phase steel.

The *Tribology Handbook* [8] provides four procedures for running in plain bearings:

1. Run at reduced load and reduced speed for a predetermined time.
2. Run at reduced speed and normal load for a predetermined time.
3. Run at reduced load and normal speed for a predetermined time.
4. Run for short times at full speed and normal load before use.

In each of the above, a less severe than normal condition is imposed on a tribosystem so that surface microgeometrical conformity and shakedown can occur.

The ground-vehicle industry has recognized the importance of running in engines effectively. Of particular concern is the piston ring/cylinder interface. Taylor, in his authoritative work on the internal combustion engine [9], states:

> The desirable degree of roughness depends on the materials used for the bore, piston, and rings, and to some extent on design details and operating regimes. Surfaces that are too rough cause rapid wear and those that are too smooth prevent fast "break-in" of piston rings and bore.

A 1964 SAE guideline [10] suggests 13 μin. RMS

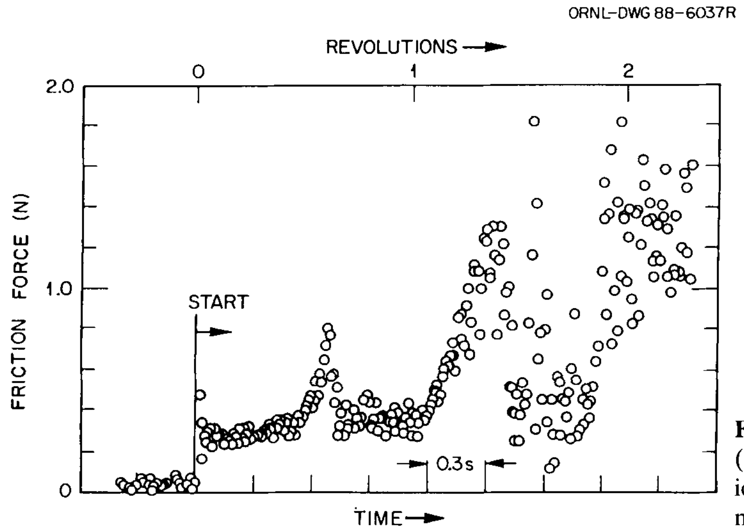

Fig. 2. Digital recording of the start of a pin (alumina) on disk (aluminum alloy) test. Spherical pin tip radius 4.76 mm, 0.98 N load, 0.1 m/sec velocity, in room temperature air.

as the appropriate finish for a cast iron cylinder bore. Plateau honing[3] is sometimes used to remove the roughest asperities on the internal surfaces of cylinders, and for certain diesel engine applications, the machined cylinder is given a commercial phosphate coating which helps lubricate the virgin cylinder surface during the initial running-in period [11]. Improvements in surface finishing procedures and treatments have reduced the need for the new owner to follow stringent running-in procedures.

In ground vehicles powered by internal combustion engines, however, it is not only the piston ring-liner tribosystem which must be run in. There are other surfaces requiring conditioning: clutches, brakes, and transmission gearing. At least a portion of the recommended running-in is meant to assure that the whole automotive drive train and brakes are also properly conditioned. It is commonly advised to operate a new vehicle at a variety of different speeds (up to a specified speed limit) during the first several hundred miles (kilometers) of use. A large number of surfaces are being run in simultaneously.

Sometimes, there is no active attempt made to run in a machine component, but only to monitor the degree of running-in. This can be done by monitoring the temperature of the new component and comparing it to the temperature of similar components which have been operating for longer times. Changes in the vibrational signature of the component are also signs of running-in [12], and examinations of the debris content in lubricants can provide useful information about the completeness of running-in and the approach to steady-state operating conditions [13, 14].

[3]Honing is a low-velocity, two-body (bonded) abrasive machining practice which imparts desirable finish and lay (directionality) to surfaces, particularly in the internal bores of cylindrical components like bushings and cylinders.

Running-in is usually associated with changes in surface roughness; however, there are other factors besides surface roughness involved during the running-in process. Some of these other factors require sophisticated instrumentation to detect, although visual evidence is often suggestive of their presence. Table 1 lists some of the changes which can occur during the running-in process.

Some of the phenomena listed in Table 1 can be monitored by studying the changes in friction which occur during running-in. A series of differently shaped friction break-in curves has been described elsewhere ([1], p. 271 ff.). These curves indicate the changes in the sliding resistance of contacting surfaces as various processes develop simultaneously during sliding. For example, the curve in Figure 2 (an alumina ball sliding on a polished aluminum alloy disk) suggests that some initial surface species such as a thin oxide film or contaminants are removed by sliding, then transfer of aluminum to the slider occurs leading to a rise in friction coefficient from self-mated sliding.

Friction running-in curves can also suggest changes in the effects of surface finish on the wear of the materials. In the course of performing a series of pin-on-flat, reciprocating friction, and wear experiments on plasma sprayed tungsten carbide–cobalt coatings, the effects of surface preparation on friction break-in and wear were clearly observed. Two specimens of Mach 2 plasma sprayed tungsten carbide–cobalt coatings on stainless steel substrates were provided to our laboratory. The surfaces had been prepared by the producer using a 600 grit abrasive grinding wheel as the final finishing step; however, as Figure

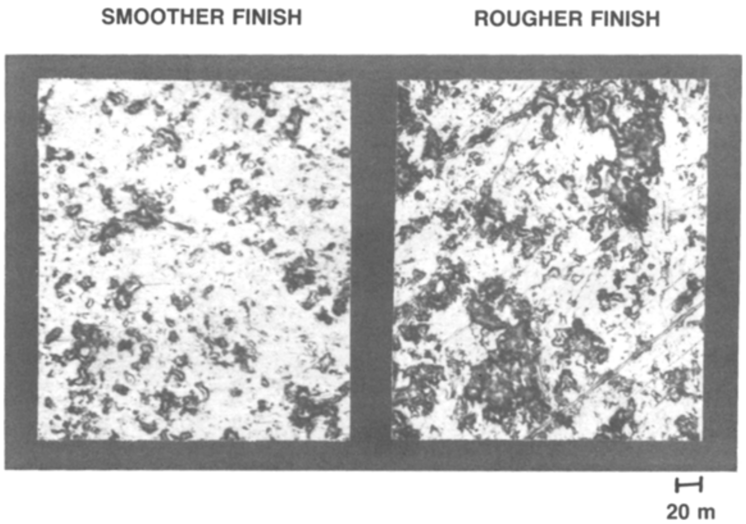

Fig. 3. Surface finishes of two plasma sprayed coupons which were ground on 600 grit abrasive. The amount of material pull-out varied between the two coupons even though they were sprayed in the same lot.

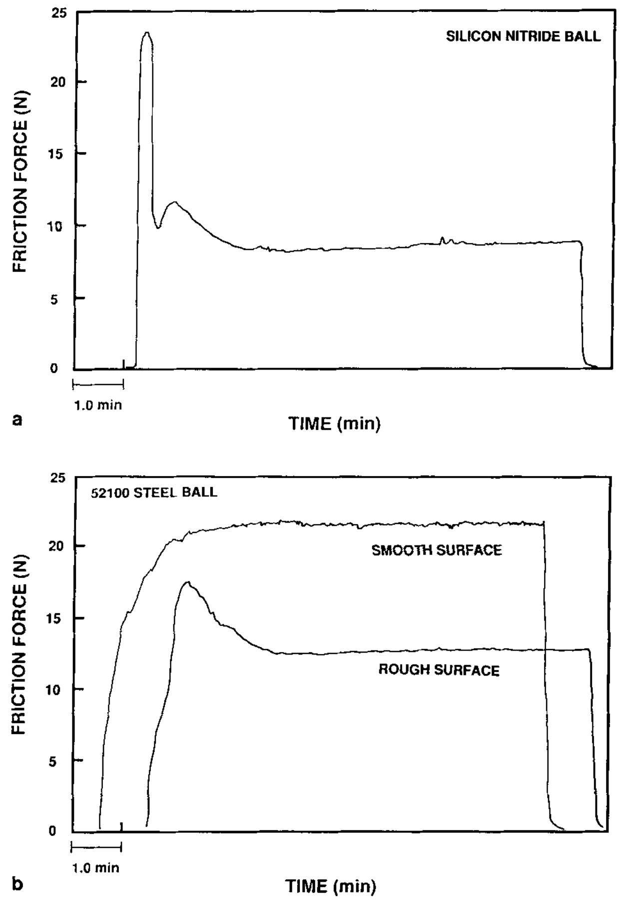

Fig. 4. The RMS (smoothed) friction records for reciprocating sliding tests on plasma sprayed coupons: (a) silicon nitride slider ball, (b) behavior of the steel sliders on smooth and rough coupon surfaces.

3 indicates, a significant difference between the surface appearance of the two coupons could be observed. Silicon nitride and 52100 steel balls were used as sliders on these coupons, and experimental conditions were:

oscillating motion
25.0 N normal load
10.0 Hz oscillating rate
10.0 mm stroke length
10.0 min test duration (120 m sliding distance)
9.52 mm slider ball diameter
air at room temperature and relative humidity 74–78%

Figure 4(a) shows the shape of a typical chart record for the RMS friction force for silicon nitride sliding tests on either of the two coupons. There was no significant difference from one coupon to the other for this slider material. For the 52100 steel sliders, there was a significant difference in the chart records obtained on the two coupons, as shown in Figure 4(b). Repeat tests with fresh steel balls verified this difference between test coupons.

Wear volumes for the slider balls were calculated from the diameter of the wear scars, and wear volumes for the flat specimens were calculated from the scar length and the cross-sectional area of the wear tracks determined using stylus profilometry. The wear volumes of both ball materials and flat materials differed much more for the steel sliders than for the silicon nitride sliders from one flat coupon to the other. Table 2 summarizes these wear results.

As shown in Table 2, the silicon nitride suffered much less effect of coupon surface roughness than did the steel. In fact, for the steel, the ratio of ball wear volume to flat wear volume was on average 0.96 on the smoother coupon and 5.56 on the rougher coupon. The difference in the break-in curve shape

Table 2. Wear Data for 52100 Steel and Silicon Nitride on WC–Co Plasma Sprayed Coatings

Coupon Finish	Ball Material	Wear Volume Ball	(___ $\times 10^{-3}$ mm^3) Coupon
Smooth	Silicon nitride	36.3	45.6
Rough	Silicon nitride	52.5	65.4
Smooth	52100 steel	1.53	1.14
	52100 steel	1.26	1.77
Rough	52100 steel	18.1	3.15
	52100 steel	18.1	3.36

suggested that a different set of surface wear processes were operating on the two coupons. Silicon nitride may not have shown this difference because it wore in a more abrasive fashion, producing a fine, powdery debris; whereas the steel ball wear process more directly involved the shaving off of material by the edges of the surface pores and the acceleration of self-mated wear by ferrous debris deposits clinging to the more porous surface.

Systematic studies of running-in may have been conducted in private industry; however, it is rare to see the results published. Having developed a method to run in machinery, the organization is often unwilling to publish the information. Interestingly, it is the Soviet literature which contains the most published research on the subject of running-in, and there is even a standard for assessing the running-in ability of materials [15]. Earlier, Kragelskii [16] described the term in the rather specific context of friction materials for brakes as follows:

> **running-in ability**—The friction surfaces must be able to "run in" fairly rapidly so that during the first application of the brake, the braking torque is not less than 80 per cent or not greater than 120 per cent of the calculated value; no scoring marks should form on the friction surface.

In his later book, he provides a method for calculating running-in time [17]. This is based on an incremental step loading procedure.

One situation which is frequently ignored in the running-in literature is that of rerun-in. Rerun-in may occur under a number of possible circumstances. For example:

- replacing or refinishing only one of two members of a wear couple
- changing the load or velocity of a component currently in operation
- a wear part is subjected to a momentary overload in service and must reestablish the steady state operating condition
- changing the lubricant but not the wear parts in a machine

While it may be argued that some of the situations above may be considered transitions instead of rerun-in, it still is quite likely that such occurrences could produce momentary increases in the friction and/or wear of the machine, or worse, set up a condition which reduces the performance.

The problem with some of the fundamental treatments of running-in is that theoretical results are generally verified for a specific testing situation.

How a tribological contact runs in is very much a function of the specific system of which the contact is a part. The running-in characteristics of the materials cannot be separated from the mechanical behavior of the surrounding machine, and this fact must be recognized when attempting to interpret and compare the results of one running-in study to another. In some cases, trends can be instructive. For example, it may be useful to know that the humidity of the environment may, in some cases, affect the running-in more than the surface finish of the mating parts. However, one should be very cautious in applying the results from work on one tribosystem to those of another. While it may be possible to develop predictive models for the running-in of particular components, it is highly unlikely that universally applicable models for running-in will be developed in the near future.

Summary

Running-in practices vary greatly: In some cases, a trial and error procedure is developed, while in other cases, the running-in friction and wear transients are allowed to occur without special attention. Very little is published in the Western literature specifically about running in. Some information is kept within private industry. There is also a very small amount of basic research going on in running-in, and this is unfortunate because understanding the early stages of contact behavior can establish a fuller understanding of the sliding process as a whole. When conducting friction and wear tests, it is advisable to determine whether the running-in stage has had a significant effect on the final results, or whether its effects can be neglected for practical purposes. It must be recognized that running-in is not only a characteristic of the materials involved, but a characteristic of the whole tribosystem; therefore, any future models for running-in must contain both material and system related variables.

Acknowledgments. The author wishes to acknowledge the support of EG & G, Inc., Idaho National Engineering Laboratory, for the work on plasma-sprayed materials. The help of J. Kniblow, INEL, is appreciated.

References

1. P.J. Blau, *Friction and Wear Transitions of Materials: Break-in, Run-in, Wear-in*, Noyes Pub. (1989) p. 268.
2. E.J. Abbott and F.A. Firestone, "Specifying Surface Quality," *Mech. Eng.*, Vol. 55 (1933) pp. 569–572.
3. K.L. Johnson, "A review of the Theory of Rolling Contact Stresses," *Wear*, Vol. 9 (1966) p. 4.
4. H. Czichos, *Tribology*, Elsevier, Amsterdam (1978) p. 163.
5. "Lubricants: Assembly and Running-in," *The Thomas Register*, Products and Services, Vol. 6 Thomas Publishing Co. (1987) p. 10991.
6. G. Heinicke, *Tribochemistry*, Carl Hanser Verlag, Munich (1984) p. 97.
7. Ref. [1], p. 333.
8. W.C. Pike, in the *Tribology Handbook*, M.J. Neale, ed., John Wiley and Sons, New York (1973) p. B 30.
9. C.F. Taylor, *The Internal Combustion Engine in Theory and Practice*, Vol. 2, MIT Press (1987) p. 471.
10. *SAE Handbook*, annual publication of the Soc. for Automotive Engineers, New York (1964).
11. M. Naylor, Cummins Engine Company, personal communication.
12. G.M. Milner, J. Leach, and R. Smith, "Development of an Automatic Machinery Vibration Analysis (AMVA) System," in *Detection, Diagnosis and Prognosis of Rotating Machinery*, T.R. Shives and L.J. Mertaugh, eds., Cambridge U. Press (1988) pp. 237–248.
13. R.V. Kadyszewski, "Advanced Quantitative Debris Monitoring, Debris Data Processor—A Tool for Enhanced Weapon System R&M Readiness," in Detection, Diagnosis and Prognosis of Rotating Machinery, T.R. Shives and L.J. Mertaugh, eds., Cambridge U. press (1988) pp. 271–279.
14. A. Corso and R. Adamo, "The Application of Ferrography in Monitoring Motor Oils During Engine Development," Lubrication Engineering, Vol. 45 (9) (1989) pp. 557–564.
15. I.V. Kragelskii, *Friction and Wear*, Butterworths, Washington (1965) p. 303.
16. "Experimental Evaluation of the Running-in Ability of Materials," GOST 23.215-84, State Committee for Standards, U.S.S.R. (1984).
17. I.V. Kragelskii, M.N. Dobychin, and V.S. Kombalov, *Friction and Wear Calculation Methods*, Pergamon Press, Oxford (1982) p. 297.