The main results of investigations of direct (effect of the friction and wear processes on the variation of the fatigue resistance characteristics) and reversed (effect of cyclic stresses on intensification of wear) effects are presented. The diagram of limiting states of the force systems characterized by complex-wear-fatigue-damage is analyzed. The problems of calculating the strength and endurance of these systems are discussed. It is shown that, in particular, in contact-mechanical friction (CMF) and friction-mechanical fatigue (FMF) under specific conditions the force systems can operate reliably with a strength margin factor smaller than unity. An equation for calculating the endurance and FMF is derived.

In this work, we analyze several relationships governing direct and reversed effects. These effects were defined in Report 1 [1]. The problem of the limiting states of force systems is also discussed.

Direct Effect. Generalizing the available experimental data, the effect of contact pressure \( q \) on the relative endurance of specimens \( \frac{N_a(q)}{N_a} \) can be described as shown in Fig. 1. The endurance in wear-fatigue tests \( N_a(q) \) can both increase and decrease in comparison with endurance \( N_a \) in conventional fatigue (MF)*. This depends on the value of \( q \) and test conditions. For example, in FF the endurance is always lower than MF. An increase of endurance in FMF in comparison with endurance in MF is observed only in a narrow range of variation of \( q \) in the conditions of lubrication with fresh oil, whereas in CMF this range is very wide. The form of the curves shown in Fig. 1 can be easily explained by corresponding variations of the hardening-softening processes in connection with the conditions of wear-fatigue tests.

According to experimental data [2], the increase of \( N_a(q) \) in CMF in comparison with \( N_a \) can (depending on the value of \( q \)) be equal to tens of times. A reduction of \( N_a(q) \) in FF in comparison with \( N_a \) may reach a factor of 10-100 or more [3].

The theoretical analysis of the direct effect was carried out in a number of investigations. For example, in FMF of a metal-polymer force system the endurance \( t_a(q) \), expressed in time units, can be computed from the equation [4]

\[
t_a(q) = \frac{U_0}{R_T^* - \alpha_T T} \left( 1 + K_w \right) \frac{R_p}{C_f b_f},
\]

(1)

where \( R_T^M, R_T^*, C_f, b_f, \alpha_T, \alpha_T^* \) are the parameters of coefficients; \( U_0 \) is the rupture energy of an interatomic bond; \( T \) is the temperature in the contact zone determined by all heat sources; coefficient \( K_w \) is a function of the main parameters describing the friction conditions and contact interaction of the elements of the system. Since \( (1 + K_w) > 1 \), Eq. (1) predicts the damaging effect of dry sliding friction.

It may easily be seen that Eq. (1) is in fact one of the possible realisations of Eq. (6) in Report 1 [1].

Fracture mechanics methods are used to calculate the endurance or endurance limit in FF.

*The notations are explained in Report 1 [1].
An engineering method of calculating FF on the basis of linear fracture mechanics was proposed in [5]. It is assumed that the model [6], developed for a half-plane and based on analysis of the stress intensity factors in separation $K_I$ and shear $K_{II}$ for an edge crack, located in a plate normal to its surface (Fig. 2) can be used to calculate real components. Although in [6] analysis was carried out for static stresses, it is assumed that the resultant stress intensity factors

$$\frac{K_I}{K_Q} = (1 - e^2)(0.8240 + 0.0637e - 0.8430e^2 + 15.41e^3 + 53.38e^4 + 59.74e^5 - 21.82e^6);$$

$$\frac{K_{II}}{K_I} = -(1 - e^2)(1.294 - 1.184e + 5.442e^2 - 28.14e^3 + 41.80e^4 - 22.38e^5 + 3.16e^6);$$

$$\frac{K_I}{K_F} = (1 - e^2)(1.2943 + 0.0044e + 0.1289e^2 + 10.89e^3 - 22.14e^4 + 10.96e^5)$$

(2)

(3)

(4)

can also be used for alternating stresses. Here $K_Q = Q/((\pi l)^{1/2}$ and $K_F = F/((\pi l)^{1/2}$ are parameters determined by the normal $Q$ and tangential $F$ loads on the sheet containing an edge crack with length $l$; $e = b/(b + l)$; $b$ is the distance from the crack to the start of distributed loading (pressure), Fig. 2.

It is assumed that crack growth is determined by the maximum tensile stress factor $K_r$. The crack will propagate within the limits of a single load cycle under angle $\alpha$ to its initial direction along an area on which maximum tensile stresses form. Parameter $l$ is the effective crack depth equal to the projection of its true length onto the normal to the surface of the component. The values of $\alpha$ and $K_r$ are determined from the equations [7]

$$\alpha = \arctg \left[ 1 - \sqrt{1 + 8(K_{II}/K_I)^2} \right] 4K_{II}/K_I];$$

$$K_r = \cos^2(\alpha/2) K_I \cos(\alpha/2) - 3 K_{II} \sin(\alpha/2).$$

The growth rate of the fatigue crack is determined using the expression [8]

$$dl/dn = c[K_{max}(1 - R)^m] - K_{II}]^m;$$