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Recoil Reactions of Casings and Efficiency Factors of Impact Machines

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Abstract: The equations have been derived for analysis of recoil reaction of machine casings as a function of kinetic energy of striker, its weight, impact velocity, surface areas of impact impulses, operation cycle time of accelerating device, and efficiency factor at various weights of actuator and casing. Theoretical analysis has made it possible to determine practical approaches to decrease recoil reaction of casing by dynamic pressing of machine to processed medium or static increase in casing weight. Scientific novelty of such approach has been verified by invention certificates.

Index Terms: dynamic pressing, impact processes, impulse of force, kinetic energy.

I. INTRODUCTION

Numerous works are devoted to investigation into impact processes [1], [2], most of them are concentrated on consideration of wave processes, achievement of required forces and accelerations, prediction of strength and design of impacted parts: striker, tool, dampers. However, these works are insufficient, their number is significantly less than in adjacent field: theory of vibration, though, upon impact there occur various and complex transformations of energy characterized by significant quantitative and qualitative differences with other types of impacts: high instant powers, deformation waves, kinetic energies of particles and centers of mass, and others. This work discusses the integral dependencies of impulse of forces during striker acceleration to impact velocity V and occurring recoil reactions of machine casing, the influence of their weights, cycle time. Solution of the formulated issues would enable development of machinery with reduced recoil of casing, with decrease in harmful vibration and increase in efficiency factor.

II. FORMULATION OF THE PROBLEM

Using the fundamentals of mechanics for material points, that is, the laws of variation and reservation of impulse of force, and kinetic energies of casing and striker, it is possible to determine recoil reaction as a function of the main constituents: weight ratio, acceleration velocities, cycle time, energy loss upon recoil of casing, coefficient of energy transfer. Analysis of the obtained dependences makes it possible to optimize designing of impact machines.

III. METHODS

The Newton, Huygens, Carnot, Euler equations are applied as well as the bases of modern theory of impact for deformed solids with consideration for wave processes in bodies and variable coefficient of recovery, that is, the fundamentals of mechanics for material points, the laws of variation and reservation of impulse of force, and kinetic energies of casing and striker.

IV. THEORETICAL PART

The impulse of recoil reaction forces upon acceleration of striker from 0 to the velocity V is:

$$P=\frac{2T}{V}, \tag{1}$$

where $T=\frac{m_1 V^2}{2}$ is the kinetic energy of striker with the weight m1.

According to Eq. (1), at maximum allowable impact velocities the recoil reaction is minimum, hence, the vibration is minimum. At one and the same impact energy, the increase in striker velocity decreases recoil reaction, herewith, the striker weight decreases to the second power. In an ideal operation cycle the R_u is constant acting as recoil reaction of casing:

$$R_u=\frac{P}{T_u}, \tag{2}$$

where Tu is the time of full operation cycle of impact machine comprised of the time of impact and the time between impacts; P is the impulse of impact at the contact point between striker and processed medium.

In actual operation cycle the parameter *Rи* is the variable resulting in formation of harmful vibrations. In order to decrease these loads and to approach ideal operation cycle, it is required to provide dampers with high damping decrement between machine casing and operator handle. Preliminary deformation of damper should approach such level when recoil reaction of casing is on average the same as upon ideal operation cycle. Overload amplitude upon vibrations will approach zero, provided that the damper rigidity in the time $T_и$ approaches zero, that is, $\alpha \to 0$, where $tg\alpha=\frac{R_{\max}-R_{\min}}{R_u}$, R_{max} and R_{min} are the maximum and the minimum reactions of casing to retention members. Maximum compression of damper X_m can be determined on the basis that the kinetic energy of casing with the weight M upon recoil at the velocity V equals to compression work of damper:

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$$R_u \cdot X_m = \frac{MV^2}{2} \quad (3)$$

Taking into consideration that the velocity is $V = \frac{P}{M}$ and $R_u = \frac{P}{T_u}$, we have as follows:

$$X_m = \frac{P \cdot T_u}{2M} \quad (4)$$

The maximum averaged compression of damper is directly proportional to the impact impulse, the cycle time, and is inversely proportional to the weight of casing, and the reaction force of casing is directly proportional to the impact impulse and inversely proportional to the cycle time.

If instead of $T_и$ the impulse frequency per second $k_y = \frac{1}{T_u}$ is substituted, then we obtain the following:

$$R_и = k_y \cdot P\ ;\ X_m = \frac{P}{2k_y M}\,. \quad (5)$$

Therefore, the damper design is selected on the basis ofEqs. (1)–(5) approaching zero rigidity. Herewith, the increase in the weight of casing decreases the recoil velocity V and the compression of damper X_m but increases the machine weight and efficiency factor. Therefore, while designing an impact machine, it its required to select such weight of the casing that to retain efficiency factor and not to overweigh the casing; the efficiency factor of impact machine depends on the efficiency factor of energy transfer upon impact of striker with tool, on energy loss during acceleration, on overall operation cycle time and other constituents. During acceleration of actuator, the efficiency factor of energy transfer can be determined as the ratio of kinetic energy of actuator to cumulative kinetic energy of actuator and machine casing. Considering that $|m_1V| = |MV_k|$ and $V = \frac{P_0}{m_1}, V_k = \frac{P_0}{M}$ where V_k is the velocity of machine casing, P_0 is the impulse of forces accelerating the weights m_1 and M in opposite directions, then the efficiency factor is:

$$\eta_1 = \frac{m_1V^2}{m_1V^2 + MV_k{}^2} = \frac{M}{m_1+M}\,. \quad (6)$$

In addition to loss of kinetic energy of casing recoil, it is required to consider for efficiency factor of energy transfer upon striker impact with tool η_2. Then the efficiency factor of impact machine will be: $\eta = \eta_1 \cdot \eta_2$.

It follows from Eq. (6) that for the efficiency factor close to unity, it is required that the casing weight is significantly higher than the weight of accelerating actuator. If this is not valid, then most of the energy is used for kinetic energy of casing recoil.

Let us consider variation of efficiency factor of energy transfer upon impact of body with the weight m_1 at the velocity V_1 against stationary before the impact body with the weight m_2>m_1. Then the impact velocity is $V_0 = V_1 - V_2 = V_1$. Two cases are of interest:

1 - the impacted bodies are of the same acoustic length;

2 - the bodies have equal wave resistances. The weight ratio $\frac{m_2}{m_1}$ is the same.

Case 1. The acoustic lengths of bodies are $\frac{l_1}{a_1} = \frac{l_2}{a_2}$ where l_1, l_2 are the lengths of the first and the second body, respectively; $a_{1,}a_2$ are the propagation velocities of longitudinal waves along the first and the second body. The recovery coefficient is $K \approx 1$.

The velocities of bodies after impact are $U_1 = \frac{m_2-m_1}{m_1+m_2}V_1$; $U_2 = \frac{2m_1}{m_1+m_2}V_1$. The momentum transferred to the second body is:

$$P = m_2 \cdot U_2 = \frac{2m_1m_2V_1}{m_1+m_2}\,. \quad (7)$$

The transferred kinetic energy is:

$$T_2 = \frac{m_2U^2{}_2}{2} = \frac{2m_1m_2}{(m_1+m_2)^2}V_1{}^2\,. \quad (8)$$

The efficiency factors of kinetic η_k and cumulative energy η (internal and kinetic) from m_1 to m_2 at K ≈ 1 are as follows:

$$\eta_k = \eta = \frac{T_2}{T_0} = \frac{T_0-T_1}{T_0} = \frac{4m_1m_2}{(m_1+m_2)^2}, \quad (9)$$

where $T_1 = \frac{m_1U_1{}^2}{2}$, $T_0 = \frac{m_1V_1{}^2}{2}$.

Case 2. The wave resistances of the bodies are equal, that is, $\lambda = \frac{\rho_2 a_2 s_2}{\rho_1 a_1 s_1} = 1$, where ρ_i, a_i, s_i are the density, the propagation velocity of longitudinal waves, and the surface area of transversal cross section of the first i=1 and the second i=2 body, respectively. The recovery coefficient is $K = \frac{m_1}{m_2}$. The velocities of bodies after impact are $U_1 = 0$. The momentum, the kinetic energy, the efficiency factor of energy transfer are: $P_2 = m_1V_1$; $T_2 = \frac{lm_1{}^2}{2m_2}V_1{}^2$, respectively, where $l = \frac{l_2}{l_1}$; $\eta_k = \frac{m_1}{m_2}$; and $\eta = 1$.

Therefore, for better transfer of momentum and kinetic energy to the second body, it is required that the impacted bodies have equal or similar acoustic lengths. If it is required to transfer maximum cumulative energy, then upon designing impacted bodies, it is attempted to obtain the recovery coefficient $K \to \frac{m_1}{m_2}$ and $\lambda \leq 1$.

V. RESULTS

The weight of casing can be intentionally increased by connecting other weights directly to the casing during operation using supports and other devices which can be either static or reactive. Binary hose can be proposed as a reactive device where jet direction varies by 180° connecting it to the casing of impact facility [3]. According to the Euler equation, the reaction is $R = 2\rho SV^2$, where ρ is the density, S is the surface area of jet transversal cross section, V is the jet velocity. In the case of, for instance, dense salt solution $\rho \to 5 \cdot 10^3$ kg/m³, surface area of jet transversal cross section $S = 4 \cdot 10^{-4}$ m², jet velocity V=10 m/s we obtain the reactive force R which presses the impact machine casing to processed medium equaling to R = 400 N. The concept of this invention is used at present for lifting bathing people by means of flexible hose.

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Such device becomes more and more popular everywhere. Herewith, the main lifting force is not the reactive thrust of water dropping from the hose but the reaction of pipe bent by 180° as in the mentioned patent description.

VI. DISCUSSION

The obtained dependencies make it possible to search for design approaches to impact machines with reduced recoil of casing and decrease in energy loss and weight of accelerating unit. Thus, in order to increase allowable velocity of striker impact with tool, the design with rotary head was proposed [4]. Herewith, according to Eq. (1), the increase in impact velocity proportionally decreases the recoil of casing and overall weight of design.

VII. CONCLUSION

Advances in technical innovations should provide increase in pressures, stresses, velocities, specific powers, and other variables of machinery. This work considered issues of decrease in recoil reactions of casing and increase in efficiency factor of impact machines due to increase in striker velocities; practical embodiments of such approaches were exemplified.

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