APPLICATION OF THE THEORY OF SONICS IN THE DESIGN OF PERCUSSIVE EQUIPMENT FOR ROCK CUTTING

IOSIF ANDRAS[1], ANDREI ANDRAS[2], CODRUȚ DAN PETRILEAN[3]

Abstract: In the paper, the results of researches performed in order to conceive, design and develop a sonic (resonant) percussive rock cutting device possible to be used at impact-rippers are presented. These results were possible by the extension of the theory of sonics regarding the concentrated parameters sonic nets by including in the calculus model of some non-linear elements, which are specific to the contact of percussive bit with the rock. The theoretical extensions of the problem lead to a general theory of percussive tools, based on the theory of sonics, from which, by some particularization and simplification, any percussive device can be modeled. In its whole, the paper represents the contribution of authors, aiming the revitalization, in the actual technologic environment, of the innovative and generous principles of the sonics, and in the same time a demonstration of its capacity to generating new research directions.

Keywords: Sonics, percussive tools, energy transfer

1. INTRODUCTION

The theory of sonics, created by the Romanian inventor George Constantinescu, represents one of the main integrating theories of the science, with many applications in technology and engineering. In essence, the basics of the theory consist in an extension of the electric-mechanic analogy, using the transfer of mechanical energy in the form of elastic waves in fluids, ignoring the basic postulate of the classic hydraulics which considered the fluids to be uncompressible. By the analogy with the electromagnetic energy transfer using the alternating current, an entire family of devices was developed (synchronous, asynchronous drives) and a lot of other devices (torque converter, impact ripper) etc.

[1] *Professor, Ph. D. Eng., University of Petroșani, iosif.andras@gmail.com*
[2] *Lecturer, Ph.D. Eng., University of Petroşani*
[3] *Assoc. Professor, Ph.D. Eng., University of Petroşani*

The main idea was to define the hydro-mechanical components as electric circuit elements, such as resistances, inductances and capacities, by equivalent formulas, allowing the calculation in the same manner that in the theory of electrical circuits. More than that, the theory became an interdisciplinary design philosophy, such the late upraised mechatronics. The possibility to apply the accurate theoretical considerations in technical devices was limited by the limitation of manufacturing possibilities of the period (between the two world wars).

Nowadays, the new possibilities opened by the technical and technological evolution lead to a reconsideration of the theory and an enlargement of the fields of application [4, 5].

An example of this is presented in the present paper. The basic symbolization and the classic calculation methods are avoided, because they can be found in the literature, the accent being focused on the results.

2. CONCEIVING, DESIGN AND DEVELOPMENT OF SONIC PERCUSSIVE ROCK CUTTING DEVICE

The percussive tools or impact rippers are devices used for the rock cutting, with various applications in drill-hammers, for blast-holes and drill-holes in prospective drilling, and other mining and civil engineering fields. They are usually actuated by compressed air, by hydrostatic devices or by electrical actuators.

The application of the principles of sonics in the calculus and construction of percussive devices actuated by high energy waves in fluids, the so called resonant percussive devices was earlier demonstrated by G. Constantinescu, in his basic books on the theory of sonics [1, 2, 3]. Fig. 1. Reproduced below is a schematic representation of ”sonic resonant hammer”, as in the authors’ terminology. Other applications and recent results relatives to percussive drilling devices, are presented in [6].

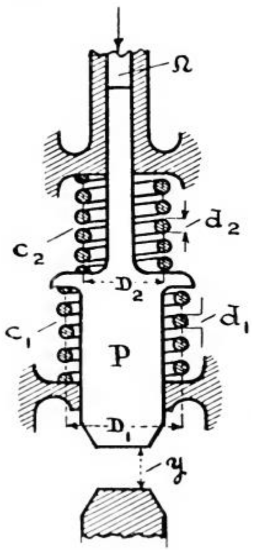

Fig. 1. Constantinescu’s sonic resonant hammer principle drawing [1, 2, 3]

In principle, a sonic impact ripper (see figure 2) consist in:

1. A sonic power generator actuated electrically (1), mechanically or hydraulically, in order to generate in the fluid high energy mechanical waves.

2. A rigid pipe (2), which lead the sonic energy towards the sonic receptor. The rigidity of the pipe is essential for the accurate transmission of the energy and the apparition of the sonic resonance phenomenon.

3. A sonic receptor (3) which consists on a sonic inductance L connected to two sonic capacities C1 and C2. The left extremity of the piston L is connected to the end of the pipe and the other pressed to the end of

the drill rig. The hydraulic sealing of the piston left end and the cavity of the pipe is essential.

The oscillating system C1 – L - C2 must be calculated in such a way that it is functioning as a resonating system, having the own natural frequency equal or near to the frequency of the exciting waves obtained in the pipe.

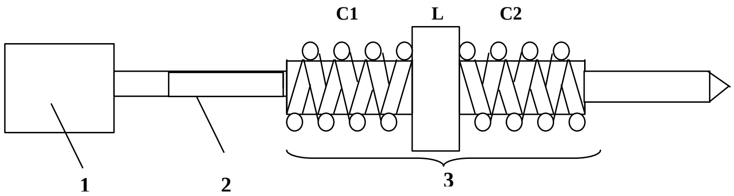

Fig. 2. Main parts of a sonic percussive device actuator
1-Sonic power generator; 2- rigid pipe; 3- sonic receptor

The effective calculation of the parameters can be performed using the classical sonic theory, the main problem being the study of the behavior of the impact ripper as an element of the complex impact ripper- rock mass system, the last one being nonlinear.

The deep analysis of the percussive rock cutting lead to the conclusion that, regardless the kind of used energy, a percussive cutting device/rock mass system consist in: pulsating force generator subsystem (1), resonating subsystem (2), energy transfer subsystem (3), cutting bit (4) and the rock (5), as is shown in the block-scheme in figure 3.

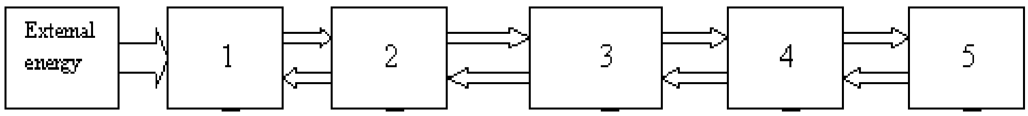

Fig. 3. Block scheme of the percussive rock cutting system
1- pulsating force generator subsystem; 2- resonating subsystem;
3- energy transfer subsystem; 4 - cutting bit; 5- rock mass.

Between the different subsystems, direct and feedback connections exist, the defining parameters being very strongly interconnected. Depending on the kind of the impact generating system, different subsystems can be materialized in common components.

The resonating system, the energy transfer system and the rock are the most interconnected elements, in a simplified model we can consider only these subsystems, having at the input a sinusoidal exciting force given by:

$$F(t) = F_0 + F_1 \sin(\varpi t + \phi) \tag{1}$$

The resonating system in the general case contains an inertia (mass) L, the springs equivalent capacity C and the resistance (damper) R, in serial connection, so the equation of the movement is:

$$L\frac{d^2x}{dt^2}+R\frac{dx}{dt}+\frac{1}{C}x=F(t) \tag{2}$$

The interaction percussive motor – cutting bit – rock is more complex, consisting in three stages: the free movement stage of the piston, in which the system is a resonant oscillating one, the percussive element (piston)-transfer element(rod) contact stage and the bit-rock contact stage.

In the bit-rock interaction, the rock is considered as a viscous-elastic element, consisting on an inertia *L*', a spring *C*' and a viscosity, *R*' which parameters are depending on the state of the contact of elements.

A very important parameter is in the stage of stabilized working regime, the ratio between the distance (gap) x1 from the end of the piston to the end of the rod, and the amplitude of free oscillations of the piston.

The mathematical model is based on the conceptual scheme shown in the figure 4.

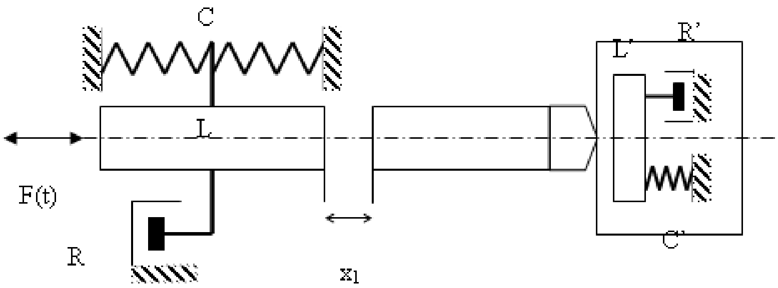

Fig. 4. The conceptual model of the percussive tool-rock mass system

On the basis of this model a mathematical model was derived, and an application in MATHCAD written, with which we can simulate different working regimes of the percussive cutting device – rock system. In figure 5, the variation of the exciting force (a) and the displacement of the piston (b) in the case of free resonant regime are shown.

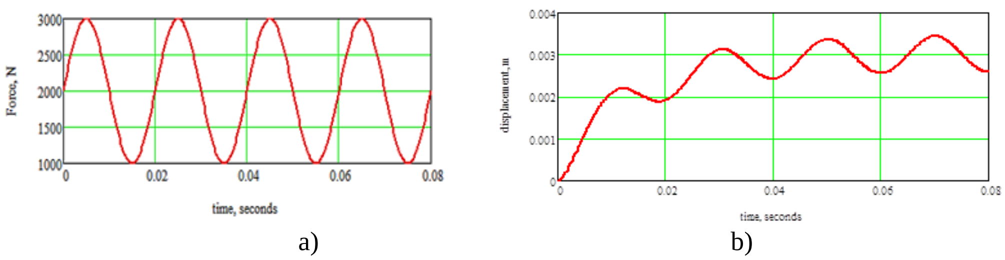

Fig. 5. Results of the free resonant regime simulation:
a) exciting force, F; b) displacement, x

After that, the influence of percussion is introduced, by modifying the parameter l1 and consequently the influence of the rock reaction. In the figure 6 the results of the simulation of this regime are shown.

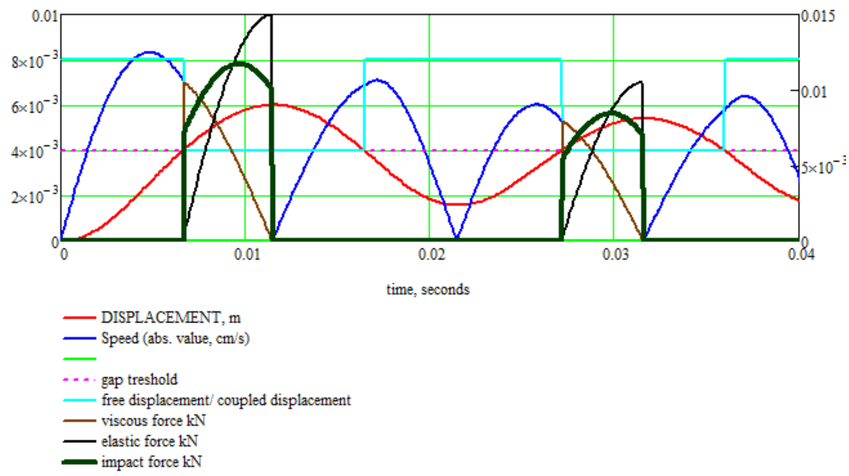

Fig. 6. Results of the simulation

We can notice the stabilized working regime of the system, the variation of the penetrating force and the frictional force, the speed and displacement variation. The initial data for the simulation are the mass *M*=5 kg, frequency 50 Hz and impact energy of 1.4 J, corresponding to an impact force of 3,79 KN.

The same elements are presented in figures 7-9 for a percussive device with 50 Hz frequency, *M*=5 kg mass, and 1,4 J impact energy.

In figure 7 the variation of the impact force in time and in figure 8, the characteristic force vs. penetration are presented.

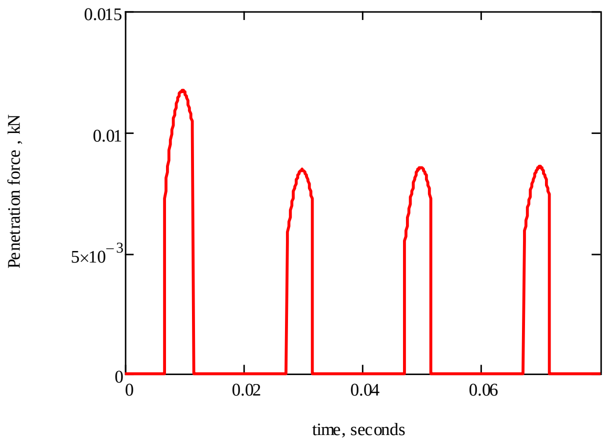

Fig.7. Variation of the penetration force in time

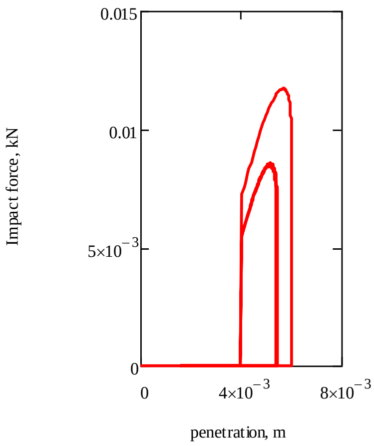

Fig.8 Penetration force vs. penetration

Based on the calculi and modeling performed, an experimental model to be tested in a testing rig will be realized

The results are compliant with those presented in [6] (fig. 9)

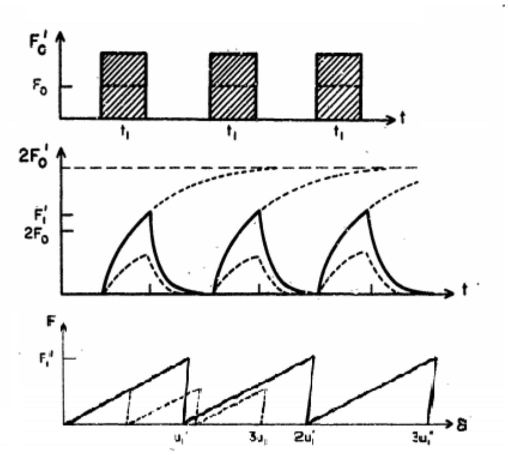

Fig. 9. Contact force vs. time and force – penetration diagram, according to [6]

3. CONCLUSIONS

In the paper, some new technical achievements induced by the application of the concepts of sonics in the contemporary technical environment are demonstrated.

The main conclusion is that in the conditions of new needs of the industry and the recent achievements of technology and science, the theory of sonics is not only a theory with some punctual applications, but a new design philosophy of technical creativity, such as mechatronics, opening the way to new technical achievements.

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