Lever-type percussive mechanisms developed by S. Abdraimov for soil compacting

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Abstract. The designs of lever-type percussive mechanisms with the largest piston-rod developed by S. Abdraimov for soil compacting are considered. The results of kinematics research of three different diagrams including the largest base drawn by S. Abdraimov are presented. Basic parameters of these diagrams are determined and recommended to create high-frequency percussive mechanisms for soil compacting.

1. Introduction
In recent years, there has been a steady tendency in the Republic of Kyrgyzstan to increase the volumes of urban and industrial construction, reconstruction of highways, etc. To implement these technological processes, foreign companies produce many types of machines and devices with electric, pneumatic and hydraulic drives. The manufacturers of such machines are BOMAG, WEBER, and AMMANN (Germany), STOW and STONE (USA) and NTC (Czech Republic) companies. In addition to foreign samples of hand rammers and vibratory plates, their Russian counterparts such as OU-60 and OU-80 (Volgodonsk), VP-3 (Saratov), UV-100 (Perm) and VU-1500 (Moscow) can be purchased [1]. The operating characteristics of existing hand rammers and vibratory plates, and the designs of foreign hand rammers are given in Table 1 and in Figure 1, respectively.

Table 1. Operating characteristics of existing hand rammers and vibratory plates

| Parameter                        | Hand ramming | Vibratory plate |
|----------------------------------|--------------|-----------------|
|                                  | WARKER BS 500 | Pneumatic IP-4503 | AMMANN IP-4502A | WARKER PS1135A |
| Impact energy, J                 | 60           | 25              | 10              | 9.3            | 10 – 50         |
| Impact frequency, Hz             | 10           | 12              | 83              | 3              | 1.6             |
| Weight, kg                       | 52           | 12              | 3               | 1.6            |                 |
| Power, kW                        | 2.3          | 3               | 210             | 540×350        |
| Capacity, m³/h                   | 300          | 200×280         | 3500            | 3000           |
| Shoe size, mm                    | 250×330      |                 |                 |                |
| Price, $                         | 3000         |                 |                 |                |
Currently, the purchase of imported hand rammers and vibratory plates is not possible for many road construction companies due to the high cost. Therefore, hard-to-reach areas are often compacted manually. However, in this case, the soil is not sufficiently compacted, subsides after 2-3 years and heavy costs for repair and restoration are involved subsequently.

In this regard, the development and creation of competitive import-substituting hand-operated soil compacting machines (hand rammers and vibratory plates) is one of the urgent problems. To solve this problem, our scientists perform research and development activities to create and improve the percussive machines and devices based on variable structure mechanisms (VSM) developed by S. Abdraimov. These mechanisms are fundamentally different from traditional ones (hydraulic and pneumatic) in their manufacturing simplicity and maintenance, they do not require hydraulic stations and compressors, highly efficient and can be operated in space [1, 2, 4].

2. The operating principle of impact unit

Recently, at the Institute of Machine Science and Automation, National Academy of Sciences of Kyrgyz Republic, several types of hand-operated soil compacting machines have been developed and created on the basis of S. Abdraimov’s VSM schemes, the design of which is shown in Figure 2a.
When creating an impact unit for hand-operated soil compacting machines, the VSM scheme with the largest piston rod was selected, in which the link lengths are interconnected by the ratio $l_2 + l_1 = l_4 + l_3$, where $l_2$, $l_3$, $l_4$ are link lengths of the crank, piston rod and rocker arm, respectively; $l_1$ is the base length. The relative sizes of links can be expressed as $\lambda_1 = l_1 / l_2$, $\lambda_2 = l_2 / l_2 = 1$, $\lambda_3 = l_3 / l_2$, $\lambda_4 = l_4 / l_2$ [1].

Figure 2. (a) S. Abdraimov’s VSM scheme with the largest piston rod and base, (b) kinematic diagram of mechanical ramming MT-2; (c) kinematic diagram of VSM with the largest base

The operating principle of impact unit of VSM-based hand rammer is as follows (Figure 2b): when electric motor 1 is turned on, its torque is transmitted through gear drive 2, 3 to the crank of length $l_2$. Rotational movement of the crank is converted by a piston rod with a length of $l_3$ into a rocking movement of the arm with a length of $l_4$. When the links of the mechanism are lined up, striker 7 mounted in rocker arm body delivers a strike to the shank of waveguide 8. Shock wave is transmitted through tamping shoe 9 to compacted soil 10.

The created machine contains no scarce materials and components, its parts and units are easy to manufacture, it is highly efficient, has minimum weight and dimensions [6]. The design of prototype hand-operated mechanical rammer is shown in Figure 3.

Figure 3. General view of prototype mechanical rammer MT-2 and vibratory plate VP-2 with VSM (a): 1—impact unit frame; 2—box; 3—tamping shoe; 4—vibration damper of handle; 5—electric motor; 6—gear wheel; 7—control handle; 8—tooth wheel; 9—gear reducer case; (b) hand rammer MT-2 with VSM; (c) vibratory plate VP-2: 1—control handle; 2—electric drive motor; 3—V-belt
drive; 4—impact mechanism; 5—swivel joint adjusting the tilt of machine impact unit; 6—compactor plate; (d) hand vibratory plate VP-1 with VSM.

### Table 2. Operating characteristics of hand mechanical rammer MT-2

| Parameter                          | Indices |
|------------------------------------|---------|
| Impact energy, J                   | MT-2    | VP-1   |
| Impact frequency, Hz              | 113–150 | 117    |
| Impact frequency, Hz              | 8–10    | 1420   |
| Electric motor rating, kW         | 1.5     | 1.5    |
| Electric motor speed, rpm         | 1420    | 600×580×750 |
| Dimensions (l×w×h), mm            | 50      | 300×200 |
| Weight, kg                        | 60      | 400×600 |
| Shoe sizes, mm                    | Up to 10|        |
| Displacement rate, m/min          |         |        |

Hand mechanical rammer MT-2 is designed for compacting cohesive and non-cohesive soils, granular materials, laying asphalt concrete during road construction in hard-to-reach areas. The operating characteristics of MT-2 are shown in Table 2.

Thus, operating and approval results of the developed VSM-based hand rammers gave rise to the idea of creating a high-frequency soil compacting machine with regard to practical recommendations and accepted restrictions that meet the specified requirements. Consequently, the power and performance of impact machines based on mechanisms of variable structure can be improved only by increasing the impact frequency, since an increase in the energy of a single impact is permissible only up to a certain limit determined by the strength of the working tool.

The results of studies of three types of S. Abdraimov’s schemes—with the largest piston rod, with the largest rocker arm and with the largest base—showed that the scheme with the largest base is the most acceptable for creating high-frequency soil compacting machines. With the same impact energy due to impact frequency, it is possible to increase the impact power and, accordingly, performance of the machine. Kinematic diagram of the recommended mechanism with the greatest base is shown in Figure 3c.

**Figure 4.** Dependences of the pre-impact and post-impact gear ratios $U_{31-}$, $U_{31+}$ and coefficient of kinematic speed recovery $R_{kin}$ on largest link coefficient $k$ of three different VSM schemes with the largest base.
The resulting graphs of dependences of gear ratios and speed recovery coefficient \( R_{\text{kin}} = \frac{U_{31+}}{U_{31-}} \) on the coefficient of largest link \( k = \frac{\lambda_0}{\lambda_1} \) in three different VSM schemes with the largest base are shown in Figure 4. These kinematic parameters characterize the effectiveness of impact on the machinable environment. These dependencies allow selecting schemes and ratios of the lengths of mechanism links and implementing them in percussive machines for different application areas with regard to specified requirements and restrictions.

It should be noted that in the above soil compacting machines, the frequency of impacts ranges from 8 to 12, and the strength of the working tool limits the linear speed of the striker. Due to the large gear ratios, linear speed of the impact unit will be high. Taking into account the strength conditions, its value is allowed no more than 10 m/s. In the proposed scheme, the value of gear ratios does not exceed unity, and the frequency of impacts is several times greater than in the scheme with the largest piston rod and rocker arm.

Based on the features of schemes with the greatest base, they can be recommended in vibratory impact devices for compacting working mixtures. For soil compacting machines, the scheme with a \( l_2 < l_4 < l_3 < l_1 \) ratio and parameter \( k = 2 \) having high impact energy and reactions in supports can be recommended, but the coefficient of kinematic speed recovery should not exceed 0.2 [5].

3. Conclusions
The comparative analysis of existing compacting machines manufactured domestically and in foreign countries enabled to identify and recommend schemes with rational kinematic parameters to create compacting machines based on variable structure mechanisms developed by S. Abdraimov for specific application areas.

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