

Original Research Paper

# Kinematics and Forces to a New Model Forging Manipulator

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**Abstract:** Forging manipulators have become more prevalent in the industry of today. They are used to manipulate objects to be forged. The most common forging manipulators move on a railway to have a better precision and stability. Heavy payload forging manipulators systems are normally characterized by a large load output and a large capacitive load input as well. The relationship between outputs and inputs will greatly influence the control and the reliability. The great advantages are the decreasing energy consumption (during furnace operation) and the avoidance of damage to the furnace door, furnace lining, or the electrodes. Furthermore, an operator does not need to be in the hazardous area near the furnace. The compact design of these systems charging, stoking and distributing machines, along with a special lever system, allows these machines to be used in the most limited areas. The robust system machine presented in combination with the powerful drives system guarantees all the needed forces and accelerations. In contrast to solutions with rebuilt forklift trucks, the new machines discussed here provide unlimited view onto the working area, effective protection of the machines hydraulic to furnace heat radiation and clearly lower maintenance expenses. Furnace production and output increase while energy consumption and electricity cost go down. Furthermore, damages to the furnace door, furnace lining or the electrodes are avoided. Moreover, operators are better protected because nobody has to stay in hazardous area of the furnace. These machines use a monorail that allows charging, stoking and distributing from all positions. Additionally the rail leads to a service or parking positions for maintenance work in a protected area. On request the monorail may be extended so that one machine can work at several furnaces. New automatic machines may offer an alternative to rail-bound ones providing a fully automated variation of the mobile charging and stoking operations. In this study the general kinematics and forces of the main mechanism of one described manipulator have been analyzed.

**Keywords:** Forging Manipulators, Kinematics, Forces, Main Mechanism, Pipe, Process Control, Railway, Furnace, Hydraulic Systems

## Introduction

Currently we are standing on the edge of a fourth industrial revolution, enabling us to make the worlds of

production and the “Internet of Things”, which could connect embedded system production technologies and smart production processes. Forging manipulators have become more prevalent in the industry of today. They are

used to manipulate objects to be forged. The most common forging manipulators are moving on a railway to have a greater precision and stability. Heavy payload forging manipulators systems are normally characterized by a large load output and a large capacitive load input as well. In this study the authors analyze the mechanics of the new manipulators systems (Dango and Dienenthal) equipped with an automatic system machine able to perform all operations (charging, stoking and distributing work) in accordance with all the requirements of the metallurgical needs.

The relationship between outputs and inputs will greatly influence the control and the reliability. The great advantages of these automated systems are the decreasing energy consumption during furnace operation and the avoidance of implant damage such as furnace door, furnace lining, or the electrodes. Furthermore, an operator does not need to be in the hazardous area near the furnace.

Quite often the space on the furnace platform is limited and needs compact and maneuverable vehicles. A more compact design of these charging, stocking and distributing machines, along with a specific lever system, could allow the use of these machines in the most limited areas. The machine driver does not need to leave the control stand for the operations of changing the stoking tool against the charging box. By means of the box, charging material can be brought to specific points in the furnace.

In the operation of pipes stocking, all the materials may be distributed optimally with the help of the specific loading tool. The same tool can be used for deep stocking, breaking of the slag bridges or opening of gas bubbles when the machine is standing (or even during travelling utilizing the mass energy) just operating with the system of levers. This sturdy system machine guarantees all the needed forces and acceleration when combined to powerful drives system. In contrast to solutions using traditional forklift trucks, these new machines (i.e., Dango and Dienenthal manipulator shown in Fig. 1) could provide unlimited view onto the working area, effective protection of the hydraulic mechanisms against the heat radiation of the furnace and decreased maintenance expenses.

The monorail allows charging, stoking and distributing from all positions. Moreover, the rail system allows service or parking positioning in protected areas for maintenance. If needed, the monorail may be extended so that one machine can serve several furnaces.

Automatic machines may represent a valid alternative to rail-bound ones. The systems discussed in this study offer a fully automated variation of the mobile loading and stocking machine.

The general kinematics and forces of the main mechanism of a manipulator are analyzed in this study. The work performed an original study of the moving parts and of the forces starting from the basic

mechanisms of these machines (Fig. 1), (Yan *et al.*, 2009; Zhao *et al.*, 2010; Gao *et al.*, 2010; Li and Liu, 2010; Ge and Gao, 2012; Petrescu, 2014; Petrescu and Petrescu, 2011; 2012a; 2012b; 2013; Petrescu *et al.*, 2009).

### *The Processing “Plastic Deformation of the Metal Materials”*

The deformation of the plastic matrix is a processing method by which, in order to obtain finished parts or parts, carry out a permanent deformation of the materials in the solid state (cold or warm) without cracking micro or macroscopic.

Advantages:

- Mechanical properties to be improved due to a homogeneous structures and denser
- The minimum amount of materials
- High accuracy for processing (especially in plastic deformation when cold)
- The possibility of obtaining complex shapes with a minimum number of operations and labor reduced
- Possibility of automation (lines of automation flexible cells of manufacture)

Disadvantages:

- Investments higher initial as regards the machinery used
- The need for large forces for deformation

After the temperature at which takes place shall be distinguished deformation:

- Plastic deformation when warm
- Plastic deformation when cold

The deformation shall be deemed to be fine arts if the unit efforts due to the forces of technological processing are over the limit of conventional flow (unitary effort which corresponds to a deformation of the persistence of the 0.2%).

The mechanisms of plastic deformation are made by:

Strengthen (hardening) is the phenomenal assembly related to the modification of the mechanical properties, physical metals in the process of plastic deformation when cold.

Strengthening can be interpreted as due to the accumulation of elastic who creates a state of tension which hinder the process of deformations of the plastic.

Another cause of strengthening is to increase the braking movement along with the increase of the degree of deformation.

The mechanism of the deformation when warm takes place as in the case of the deformation in the cold by gliding and macling.







Fig. 1. Dango and dienthal forging manipulators

The condition of the bags characterized in particular through a resistance and stiffness increased, plasticity decreased. Is a state in which the increase of the degree of distortion is cumbersome or impossible. To prevent the occurrence of the early this status and to facilitate the process of plastic deformation will proceed with the heating of the materials.

Slip is the movement of the thin layers of the crystal relative to each other.

The walk occurs along the plane of the atomic density maximum, the distance between the two planes being approximately 1 mm. The deformation of the plastic multi crystals shall consist of the deformation of the crystals and of the deformation of the substance inter crystals. The deformation of granules in multi crystals begins with granules plans which are favorable to the axis of the unit efforts.

Macling-is the phenomenon of reorientation of part of a crystal compared with the rest of the course of a plan called the plan of macling. The selection of the crystal is called macle and appears at speeds of large deformation. The process is instantly under the action of forces tangential smaller than those of slipping.

#### *Effect of Temperature on Plastic Deformation*

Return-is the phenomenon of removing the voltages of the network and increasing plasticization of material, without producing any change in the texture depth ( $0,2Tt < tr < 0,4Tt$ , where  $t$  melting temperature).

By heating the mobility of atoms increases, found to an increase of the phenomenon of diffusion determined by the movement of the atoms during the holidays and anvil gaps, status which leads in the end to the elimination of domestic tension.

Recrystallization-occurs in the solid state and consists in the reorganization of the crystalline network deformed and the emergence of new centers of crystallization. By recrystallization is completely eliminated the internal tension, rounding off hardness, resistance to deformation and increasing the plasticity.

#### *Effect of Temperature on the Resistance to Deformation and Plasticization*

#### *The Increase in the Temperature of the Causes the Essential Changes in the Characteristics of the Resistance of the Metals*

Resistance to deformation spectacular decreases with the temperature increase due to the following phenomena:

- At high temperatures increase the oscillation amplitude atoms due to the increase in their energy potential. The atoms pass more easily from a position of balance in another
- At high temperatures resistance to deformation drops, moving and granules orientation is easier in such a way that the deformation can be made efforts

Parameters defining the heating are:

- The speed of heating (the heating temperature reported at the time of the touch of the latter)
- Speed of the cooling system (the temperature of the cooling reported at the time of the touch of the latter)
- The duration of the maintenance of the to the temperature of the bearing

### *Areas of Temperature to the Plastic Deformation when Warm*

Depending on the reciprocal influence phenomena that take place at the deformation when warm (bag return, recrystallization) they differ in the following phases:

- Plastic deformation when cold:  $TD < 0.2 t$
- Incomplete deformation when cold:  $0,2Tt < t_d < 0,4Tt$ ; the phenomenon of strengthening and at the anchorage. It is characteristic processing with high speeds deformation
- Incomplete deformation when warm  $0,4t < t_d < 0,6Tt$ ; the deformation is characterized by the complete action of the phenomenon of return and incomplete the phenomenon of recrystallization. Due to the in homogeneity of granules, the material is strong which leads to the appearance of the cracks
- Deformation when hot-is characterized by the lack of the effects of strengthening after processing and through a structure and fine homogeneous metallic material as a result of the complete the return and recrystallization

Resistance to deformation when warm is very low in the cold and plasticity is great ( $0,6Tt < t_d < 0.85t$ ). For  $0.85t < t_d$  is found overheating and the trend of the combustion chamber.

### *The Laws of Plastic Deformation*

These laws are valid at both the plastic deformation to the cold and warm.

The law is the constant volume sampler.

The volume of the half-finished subject to plastic deformation (when warm or cold) is equal to the volume of the finished part.

Regardless of the small volume by indeseare or loss of nitrogen oxides, we can consider that the volume of the finished part obtained by plastic deformation is equal to the volume of the half-finished.

This law is very important in practice, it allowing the volume calculation of half-finished subject to deformation of the plastic.

### *The Law of this Elastic Deformation During Deformations of the Plastic*

The deformation of the plastic matrix is always accompanied by one deformation elastic. We will not be in the area of the plasticity without to pass through the elasticity. (Hooke). Under the law, after processing by plastic deformation when cold appears a downward trend of the relaxation of the material. The request of the order, cease elastic deformation, which produce the “the relaxation of the “rest material, only plastic deformation.

The effects of this law shall be taken into account in the design of a tool for deformation plastic, such as molds for pulling and extrusion which always have a cone of output.

### *The Law of Minimum Resistance*

This law has several entries:

- Any form of the cross-section of a body subject to plastic deformation through the relief valve in the presence of the friction on the contact surface tends to take the form which has the perimeter of the minimum given area; at the limit tends to circle
- The movement of the body points on the surface perpendicular to the direction of the external forces takes place after the normal operation of the shortest carried at the perimeter of the section. The maximum displacement will occur in that direction in which will move the largest quantity of material

### *The Law of the Occurrence and Leveling Interior Efforts*

Any change in the shape of a body multi crystals located in the plastic status appear in the material additional efforts who oppose the deformation related and which tend to equilibrate each other.

Additional efforts are due to friction of contact between the tool and the preformed in homogeneity, chemical composition, mechanical properties, etc.

Unit efforts products and remaining in the machined part may be added the unit efforts that occur during operation, what can cause cracks or the destruction of the work piece.

In order to avoid the appearance of the additional efforts will reduce the friction between the surface of the material damaged and active area of the tool.

### *The Law of the Similarity*

For the same conditions of deformation of the two also geometric which have different sizes, specific pressures of deformation are equal between them, the ratio of the forces of deformation being equally by the square of the report linear sizes.

The law is valid for when both have the same structural phases, the same chemical and the same mechanical characteristics and the body temperature at the beginning of the deformation is the same.

### *Heating of the Metal Materials for Plastic Deformation*

By warming half-made for deformation arts is aimed at:

- Decrease the limit of flow
- The reduction of domestic tension (via the return and recrystallization)
- Mixing the structure

A correct heating shall ensure by means of:

- The shortening of the heating time until reaching the TD

- Ensuring a uniform heats
- Reducing the combustion and decarburization
- Higher values are limited by the occurrence of oxidation

The lower limit shall be established in accordance with the nature of the material.

From the point of view of the heat shield in the process of plastic deformation when warm there are three distinct stages:

- Heating stage from 0 - tid
- The stage of the deformation itself tid tsd -
- The stage of cooling

In ovens which are carried out the heating are varied from the point of view of the forms, the dimensions and of the principle of the operation. They shall be classified as follows:

1. with intermittent operation  
2. With continuous operation
1. Electrical wiring  
2. with the flame
1. in the usual atmosphere  
2. in a controlled atmosphere
1. Normal  
2. Deep

## Materials and Methods

The new manipulators systems considered in this study are those produced by Dango and Dienenthal.

### Structure, Geometry and Kinematic to a Rail-bound Forging Manipulator

Figure 2 shows the kinematics scheme of the main mechanism from a rail-bound forging manipulator (Yan *et al.*, 2009; Zhao *et al.*, 2010; Gao *et al.*, 2010; Li and Liu, 2010; Ge and Gao, 2012; Petrescu, 2014; Petrescu and Petrescu, 2011; 2013; Petrescu *et al.*, 2009).

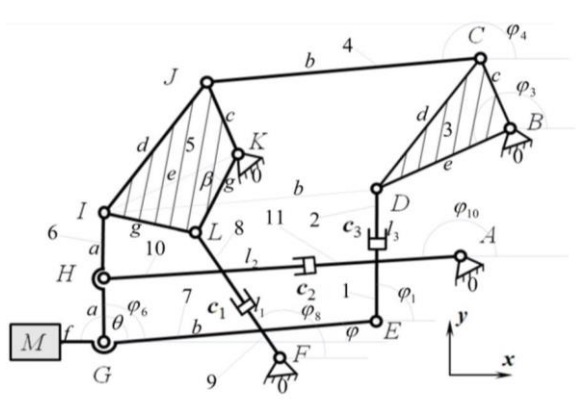


Fig. 2. Kinematic scheme of a forging manipulator main mechanism

Usually, starting from the knowledge of the constant lengths (a-g), the coordinates ( $x_B, y_B, x_A, y_A, x_K, y_K, x_F, y_F$ ) and the  $\varphi$  angle that must to be maintained constant the other variable should be determined. In direct kinematics we know  $l_1, l_2$ ; the other variable to be determined are: Intermediary  $l_3$  (by using the systems of equations I, II, III),  $\varphi_1, \varphi_3, \varphi_6, \varphi_8, \varphi_{10}$  and finally  $x_M, y_M$  (from the solution of the system IV). In inverse kinematics we know  $x_M, y_M$  and we should determine  $\varphi_1, \varphi_3, \varphi_6, \varphi_8, \varphi_{10}, l_1, l_2, l_3$  using the systems of equation I, II, III, IV. By considering four independent vector contours (KLFK, KIGEDB, AHFK, AHGM) we can write the following systems of equations (I, II, III, IV):

$$\begin{cases} (x_K - x_F) + g \cdot \cos(\phi_3 + \beta) = l_1 \cdot \cos \phi_8 \\ (y_K - y_F) + g \cdot \sin(\phi_3 + \beta) = l_1 \cdot \sin \phi_8 \end{cases} \quad (I)$$

$$\begin{cases} x_K + b \cdot \cos \phi + l_3 \cdot \cos \phi_1 = 2a \cdot \cos \phi_6 \\ y_K + b \cdot \sin \phi + l_3 \cdot \sin \phi_1 = 2a \cdot \sin \phi_6 \end{cases} \quad (II)$$

$$\begin{cases} (x_A - x_K) + l_2 \cdot \cos \phi_{10} + a \cdot \cos \phi_6 = e \cdot \cos \phi_3 \\ (y_A - y_K) + l_2 \cdot \sin \phi_{10} + a \cdot \sin \phi_6 = e \cdot \sin \phi_3 \end{cases} \quad (III)$$

$$\begin{cases} (x_A - x_M) + l_3 \cdot \cos \phi_{10} + f \cdot \cos(\phi + \theta) = a \cdot \cos \phi_6 \\ (y_A - y_M) + l_3 \cdot \sin \phi_{10} + f \cdot \sin(\phi + \theta) = a \cdot \sin \phi_6 \end{cases} \quad (IV)$$

### Inverse Kinematics

The parameters  $\varphi_1, \varphi_3, \varphi_6, \varphi_8, \varphi_{10}, l_1, l_2, l_3$  can be derived by solving the four systems I, II, III, IV. The following relationships (systems V, VI) are obtained:

$$\begin{cases} \cos \phi_6 = \frac{A_1 \cdot A_2 \mp A_3 \cdot \sqrt{A_2^2 + A_3^2 - A_1^2}}{A_2^2 + A_3^2}; \phi_6 = \arccos(\cos \phi_6) \\ A_0 = 4a^2 + (x_K + b \cos \phi)^2 + (y_K + b \sin \phi)^2 - \\ - 4a[(x_K + b \cos \phi) \cos \phi_6 + (y_K + b \sin \phi) \sin \phi_6]; l_3 = \sqrt{A_0} \\ \begin{cases} \cos \phi_1 = \frac{2a \cdot \cos \phi_6 - x_K - b \cdot \cos \phi}{l_3} \\ \sin \phi_1 = \frac{2a \cdot \sin \phi_6 - y_K - b \cdot \sin \phi}{l_3} \end{cases}; \begin{cases} \phi_1 = \text{sign}(\sin \phi_1) \cdot \\ \arccos(\cos \phi_1) \end{cases} \\ \cos \phi_{10} = \frac{a \cdot \cos \phi_6 - f \cdot \cos(\phi + \theta) + x_M - x_A}{l_3} \\ \sin \phi_{10} = \frac{a \cdot \sin \phi_6 - f \cdot \sin(\phi + \theta) + y_M - y_A}{l_3} \\ \phi_{10} = \text{sign}(\sin \phi_{10}) \cdot \arccos(\cos \phi_{10}) \\ l_2 = -A_4 \mp \sqrt{A_4^2 + e^2} \end{cases} \quad (V)$$



In order to determine the accelerations, the systems I-IV time derivative should be considered.

However, a rapid and direct method can be applied: We know now the velocities and then it is possible to directly derivate their relations from the system (5):

$$\left\{ \begin{aligned} \ddot{\phi}_3 &= \frac{\ddot{l}_1 - \dot{\phi}_3 \cdot g \cdot \cos(\phi_8 - \phi_3 - \beta) \cdot (\dot{\phi}_8 - \dot{\phi}_3)}{g \cdot \sin(\phi_8 - \phi_3 - \beta)} \\ \ddot{\phi}_8 &= \frac{\cos(\phi_8 - \phi_3 - \beta) \cdot \ddot{l}_1 - \dot{l}_1 \cdot \sin(\phi_8 - \phi_3 - \beta) \cdot (\dot{\phi}_8 - \dot{\phi}_3)}{l_1 \cdot \sin(\phi_8 - \phi_3 - \beta)} - \\ &\quad \frac{\dot{\phi}_8 \cdot l_1 \cdot \cos(\phi_8 - \phi_3 - \beta) \cdot (\dot{\phi}_8 - \dot{\phi}_3) + \dot{\phi}_8 \cdot \dot{l}_1 \cdot \sin(\phi_8 - \phi_3 - \beta)}{l_1 \cdot \sin(\phi_8 - \phi_3 - \beta)} \\ \ddot{\phi}_6 &= \frac{e \cdot \cos(\phi_6 - \phi_3) \cdot (\dot{\phi}_6 - \dot{\phi}_3) \cdot \dot{\phi}_3 + e \cdot \sin(\phi_6 - \phi_3) \cdot \ddot{\phi}_3 - \ddot{l}_2}{a \cdot \sin(\phi_{10} - \phi_6)} - \\ &\quad \frac{\dot{\phi}_6 \cdot a \cdot \cos(\phi_{10} - \phi_6) \cdot (\dot{\phi}_{10} - \dot{\phi}_6)}{a \cdot \sin(\phi_{10} - \phi_6)} \\ \ddot{\phi}_{10} &= \frac{\ddot{l}_2 \cdot \cos(\phi_{10} - \phi_6) - \dot{l}_2 \cdot \sin(\phi_{10} - \phi_6) \cdot (\dot{\phi}_{10} - \dot{\phi}_6)}{l_2 \cdot \sin(\phi_{10} - \phi_6)} - \\ &\quad \frac{e \cdot \cos(\phi_6 - \phi_3) \cdot (\dot{\phi}_6 - \dot{\phi}_3) \cdot \dot{\phi}_3 + e \cdot \sin(\phi_6 - \phi_3) \cdot \ddot{\phi}_3}{l_2 \cdot \sin(\phi_{10} - \phi_6)} - \\ &\quad \frac{\dot{\phi}_{10} \cdot \dot{l}_2 \cdot \sin(\phi_{10} - \phi_6) + \dot{\phi}_{10} \cdot l_2 \cdot \cos(\phi_{10} - \phi_6) \cdot (\dot{\phi}_{10} - \dot{\phi}_6)}{l_2 \cdot \sin(\phi_{10} - \phi_6)} \\ \ddot{\phi}_1 &= \frac{2a \cdot \cos(\phi_6 - \phi_1) \cdot \ddot{\phi}_6 - 2a \cdot \sin(\phi_6 - \phi_1) \cdot (\dot{\phi}_6 - \dot{\phi}_1) \cdot \dot{\phi}_6 - \dot{\phi}_1 \cdot \dot{l}_3}{l_3} \\ \ddot{x}_M &= \ddot{l}_3 \cdot \cos \phi_{10} - \dot{l}_3 \cdot \sin \phi_{10} \cdot \dot{\phi}_{10} - \dot{l}_3 \cdot \sin \phi_{10} \cdot \dot{\phi}_{10} - l_3 \cdot \cos \phi_{10} \cdot \dot{\phi}_{10}^2 - \\ &\quad - l_3 \cdot \sin \phi_{10} \cdot \ddot{\phi}_{10} + a \cdot \cos \phi_6 \cdot \dot{\phi}_6^2 + a \cdot \sin \phi_6 \cdot \ddot{\phi}_6 \\ \ddot{y}_M &= \ddot{l}_3 \cdot \sin \phi_{10} + \dot{l}_3 \cdot \cos \phi_{10} \cdot \dot{\phi}_{10} + \dot{l}_3 \cdot \cos \phi_{10} \cdot \dot{\phi}_{10} - l_3 \cdot \sin \phi_{10} \cdot \dot{\phi}_{10}^2 + \\ &\quad + l_3 \cdot \cos \phi_{10} \cdot \ddot{\phi}_{10} + a \cdot \sin \phi_6 \cdot \dot{\phi}_6^2 - a \cdot \cos \phi_6 \cdot \ddot{\phi}_6 \end{aligned} \right. \quad (5)$$

The last kinematics parameters of the mechanism, which gives us the complete kinematic description of the main mechanism, can be then determined. This parameter is necessary in the kinetostatic and dynamic calculations (systems 6-21):

$$\left\{ \begin{aligned} x_C &= c \cdot \cos(\phi_3 - CBD) \left\{ \begin{aligned} \dot{x}_C &= -c \cdot \sin(\phi_3 - CBD) \cdot \dot{\phi}_3 \\ \dot{y}_C &= c \cdot \cos(\phi_3 - CBD) \cdot \dot{\phi}_3 \end{aligned} \right. \\ \ddot{x}_C &= -c \cdot \cos(\phi_3 - CBD) \cdot \dot{\phi}_3^2 - c \cdot \sin(\phi_3 - CBD) \cdot \ddot{\phi}_3 \\ \ddot{y}_C &= -c \cdot \sin(\phi_3 - CBD) \cdot \dot{\phi}_3^2 + c \cdot \cos(\phi_3 - CBD) \cdot \ddot{\phi}_3 \end{aligned} \right. \quad (6)$$

$$\left\{ \begin{aligned} x_{G_3} &= s_3 \cdot \cos(\phi_3 - CBD + \alpha) \left\{ \begin{aligned} \dot{x}_{G_3} &= -s_3 \cdot \sin(\phi_3 - CBD + \alpha) \cdot \dot{\phi}_3 \\ \dot{y}_{G_3} &= s_3 \cdot \cos(\phi_3 - CBD + \alpha) \cdot \dot{\phi}_3 \end{aligned} \right. \\ \ddot{x}_{G_3} &= -s_3 \cdot \cos(\phi_3 - CBD + \alpha) \cdot \dot{\phi}_3^2 - s_3 \cdot \sin(\phi_3 - CBD + \alpha) \cdot \ddot{\phi}_3 \\ \ddot{y}_{G_3} &= -s_3 \cdot \sin(\phi_3 - CBD + \alpha) \cdot \dot{\phi}_3^2 + s_3 \cdot \cos(\phi_3 - CBD + \alpha) \cdot \ddot{\phi}_3 \end{aligned} \right. \quad (7)$$

$$\left\{ \begin{aligned} x_D &= e \cdot \cos \phi_3 \left\{ \begin{aligned} \dot{x}_D &= -e \cdot \sin \phi_3 \cdot \dot{\phi}_3 \\ \dot{y}_D &= e \cdot \cos \phi_3 \cdot \dot{\phi}_3 \end{aligned} \right. \\ \ddot{x}_D &= -e \cdot \cos \phi_3 \cdot \dot{\phi}_3^2 - e \cdot \sin \phi_3 \cdot \ddot{\phi}_3 \\ \ddot{y}_D &= -e \cdot \sin \phi_3 \cdot \dot{\phi}_3^2 + e \cdot \cos \phi_3 \cdot \ddot{\phi}_3 \end{aligned} \right. \quad (8)$$

$$\left\{ \begin{aligned} x_{G_4} &= x_C + s_4 \cdot \cos \phi_4 \left\{ \begin{aligned} \dot{x}_{G_4} &= \dot{x}_C \\ \dot{y}_{G_4} &= \dot{y}_C \end{aligned} \right. \left\{ \begin{aligned} \ddot{x}_{G_4} &= \ddot{x}_C \\ \ddot{y}_{G_4} &= \ddot{y}_C \end{aligned} \right. \end{aligned} \right. \quad (9)$$

$$\left\{ \begin{aligned} x_J &= x_K + c \cdot \cos(\phi_3 - JKI) \left\{ \begin{aligned} \dot{x}_J &= -c \cdot \sin(\phi_3 - JKI) \cdot \dot{\phi}_3 \\ \dot{y}_J &= y_K + c \cdot \sin(\phi_3 - JKI) \left\{ \begin{aligned} \dot{y}_J &= c \cdot \cos(\phi_3 - JKI) \cdot \dot{\phi}_3 \end{aligned} \right. \end{aligned} \right. \\ \ddot{x}_J &= -c \cdot \cos(\phi_3 - JKI) \cdot \dot{\phi}_3^2 - c \cdot \sin(\phi_3 - JKI) \cdot \ddot{\phi}_3 \\ \ddot{y}_J &= -c \cdot \sin(\phi_3 - JKI) \cdot \dot{\phi}_3^2 + c \cdot \cos(\phi_3 - JKI) \cdot \ddot{\phi}_3 \end{aligned} \right. \quad (10)$$

$$\left\{ \begin{aligned} x_I &= x_K + e \cdot \cos \phi_3 \left\{ \begin{aligned} \dot{x}_I &= -e \cdot \sin \phi_3 \cdot \dot{\phi}_3 \\ \dot{y}_I &= y_K + e \cdot \sin \phi_3 \left\{ \begin{aligned} \dot{y}_I &= e \cdot \cos \phi_3 \cdot \dot{\phi}_3 \end{aligned} \right. \end{aligned} \right. \\ \ddot{x}_I &= -e \cdot \cos \phi_3 \cdot \dot{\phi}_3^2 - e \cdot \sin \phi_3 \cdot \ddot{\phi}_3 \\ \ddot{y}_I &= -e \cdot \sin \phi_3 \cdot \dot{\phi}_3^2 + e \cdot \cos \phi_3 \cdot \ddot{\phi}_3 \end{aligned} \right. \quad (11)$$

$$\left\{ \begin{aligned} x_L &= x_K + g \cdot \cos(\phi_3 + \beta) \left\{ \begin{aligned} \dot{x}_L &= -g \cdot \sin(\phi_3 + \beta) \cdot \dot{\phi}_3 \\ \dot{y}_L &= y_K + g \cdot \sin(\phi_3 + \beta) \left\{ \begin{aligned} \dot{y}_L &= g \cdot \cos(\phi_3 + \beta) \cdot \dot{\phi}_3 \end{aligned} \right. \end{aligned} \right. \\ \ddot{x}_L &= -g \cdot \cos(\phi_3 + \beta) \cdot \dot{\phi}_3^2 - g \cdot \sin(\phi_3 + \beta) \cdot \ddot{\phi}_3 \\ \ddot{y}_L &= -g \cdot \sin(\phi_3 + \beta) \cdot \dot{\phi}_3^2 + g \cdot \cos(\phi_3 + \beta) \cdot \ddot{\phi}_3 \end{aligned} \right. \quad (12)$$

$$\left\{ \begin{aligned} x_{G_5} &= x_K + s_5 \cdot \cos(\phi_3 - JKI + \gamma) \\ y_{G_5} &= y_K + s_5 \cdot \sin(\phi_3 - JKI + \gamma) \\ \dot{x}_{G_5} &= -s_5 \cdot \sin(\phi_3 - JKI + \gamma) \cdot \dot{\phi}_3 \\ \dot{y}_{G_5} &= s_5 \cdot \cos(\phi_3 - JKI + \gamma) \cdot \dot{\phi}_3 \\ \ddot{x}_{G_5} &= -s_5 \cdot \cos(\phi_3 - JKI + \gamma) \cdot \dot{\phi}_3^2 - s_5 \cdot \sin(\phi_3 - JKI + \gamma) \cdot \ddot{\phi}_3 \\ \ddot{y}_{G_5} &= -s_5 \cdot \sin(\phi_3 - JKI + \gamma) \cdot \dot{\phi}_3^2 + s_5 \cdot \cos(\phi_3 - JKI + \gamma) \cdot \ddot{\phi}_3 \end{aligned} \right. \quad (13)$$

$$\left\{ \begin{aligned} x_{G_8} &= x_F + \frac{1}{2} l_1 \cdot \cos \phi_8 \left\{ \begin{aligned} \dot{x}_{G_8} &= \frac{1}{2} \dot{l}_1 \cdot \cos \phi_8 - \frac{1}{2} l_1 \cdot \sin \phi_8 \cdot \dot{\phi}_8 \\ \dot{y}_{G_8} &= y_F + \frac{1}{2} l_1 \cdot \sin \phi_8 \left\{ \begin{aligned} \dot{y}_{G_8} &= \frac{1}{2} \dot{l}_1 \cdot \sin \phi_8 + \frac{1}{2} l_1 \cdot \cos \phi_8 \cdot \dot{\phi}_8 \end{aligned} \right. \end{aligned} \right. \\ \ddot{x}_{G_8} &= \frac{1}{2} \ddot{l}_1 \cdot \cos \phi_8 - \frac{1}{2} \dot{l}_1 \cdot \sin \phi_8 \cdot \dot{\phi}_8 - \frac{1}{2} l_1 \cdot \sin \phi_8 \cdot \dot{\phi}_8^2 - \frac{1}{2} l_1 \cdot \cos \phi_8 \cdot \ddot{\phi}_8 \\ \ddot{y}_{G_8} &= \frac{1}{2} \ddot{l}_1 \cdot \sin \phi_8 + \frac{1}{2} \dot{l}_1 \cdot \cos \phi_8 \cdot \dot{\phi}_8 + \frac{1}{2} l_1 \cdot \cos \phi_8 \cdot \dot{\phi}_8^2 - \frac{1}{2} l_1 \cdot \sin \phi_8 \cdot \dot{\phi}_8^2 + \frac{1}{2} l_1 \cdot \cos \phi_8 \cdot \ddot{\phi}_8 \end{aligned} \right. \quad (14)$$



$$\left\{ \begin{aligned} x_{G_{10}} &= x_A + \frac{1}{2} l_2 \cdot \cos \phi_{10} & \dot{x}_{G_{10}} &= \frac{1}{2} \dot{l}_2 \cdot \cos \phi_{10} - \frac{1}{2} l_2 \cdot \sin \phi_{10} \cdot \dot{\phi}_{10} \\ y_{G_{10}} &= y_A + \frac{1}{2} l_2 \cdot \sin \phi_{10} & \dot{y}_{G_{10}} &= \frac{1}{2} \dot{l}_2 \cdot \sin \phi_{10} + \frac{1}{2} l_2 \cdot \cos \phi_{10} \cdot \dot{\phi}_{10} \\ \ddot{x}_{G_{10}} &= \frac{1}{2} \ddot{l}_2 \cdot \cos \phi_{10} - \frac{1}{2} \dot{l}_2 \cdot \sin \phi_{10} \cdot \dot{\phi}_{10} - \frac{1}{2} l_2 \cdot \sin \phi_{10} \cdot \ddot{\phi}_{10} - \\ & - \frac{1}{2} l_2 \cdot \cos \phi_{10} \cdot \dot{\phi}_{10}^2 - \frac{1}{2} l_2 \cdot \sin \phi_{10} \cdot \ddot{\phi}_{10} \\ \ddot{y}_{G_{10}} &= \frac{1}{2} \ddot{l}_2 \cdot \sin \phi_{10} + \frac{1}{2} \dot{l}_2 \cdot \cos \phi_{10} \cdot \dot{\phi}_{10} + \frac{1}{2} l_2 \cdot \cos \phi_{10} \cdot \ddot{\phi}_{10} - \\ & - \frac{1}{2} l_2 \cdot \sin \phi_{10} \cdot \dot{\phi}_{10}^2 + \frac{1}{2} l_2 \cdot \cos \phi_{10} \cdot \ddot{\phi}_{10} \end{aligned} \right. \quad (15)$$

$$\left\{ \begin{aligned} x_E &= x_D - l_3 \cdot \cos \phi_1 & \dot{x}_E &= \dot{x}_D - \dot{l}_3 \cdot \cos \phi_1 + l_3 \cdot \sin \phi_1 \cdot \dot{\phi}_1 \\ y_E &= y_D - l_3 \cdot \sin \phi_1 & \dot{y}_E &= \dot{y}_D - \dot{l}_3 \cdot \sin \phi_1 - l_3 \cdot \cos \phi_1 \cdot \dot{\phi}_1 \\ \ddot{x}_E &= \ddot{x}_D - \ddot{l}_3 \cdot \cos \phi_1 + \dot{l}_3 \cdot \sin \phi_1 \cdot \dot{\phi}_1 + \dot{l}_3 \cdot \sin \phi_1 \cdot \ddot{\phi}_1 + \\ & + l_3 \cdot \cos \phi_1 \cdot \dot{\phi}_1^2 + l_3 \cdot \sin \phi_1 \cdot \ddot{\phi}_1 \\ \ddot{y}_E &= \ddot{y}_D - \ddot{l}_3 \cdot \sin \phi_1 - \dot{l}_3 \cdot \cos \phi_1 \cdot \dot{\phi}_1 - \dot{l}_3 \cdot \cos \phi_1 \cdot \ddot{\phi}_1 + \\ & + l_3 \cdot \sin \phi_1 \cdot \dot{\phi}_1^2 - l_3 \cdot \cos \phi_1 \cdot \ddot{\phi}_1 \end{aligned} \right. \quad (16)$$

$$\left\{ \begin{aligned} x_{G_1} &= x_E + \frac{1}{2} l_3 \cdot \cos \phi_1 & \dot{x}_{G_1} &= \dot{x}_E + \frac{1}{2} \dot{l}_3 \cdot \cos \phi_1 - \frac{1}{2} l_3 \cdot \sin \phi_1 \cdot \dot{\phi}_1 \\ y_{G_1} &= y_E + \frac{1}{2} l_3 \cdot \sin \phi_1 & \dot{y}_{G_1} &= \dot{y}_E + \frac{1}{2} \dot{l}_3 \cdot \sin \phi_1 + \frac{1}{2} l_3 \cdot \cos \phi_1 \cdot \dot{\phi}_1 \\ \ddot{x}_{G_1} &= \ddot{x}_E + \frac{1}{2} \ddot{l}_3 \cdot \cos \phi_1 - \frac{1}{2} \dot{l}_3 \cdot \sin \phi_1 \cdot \dot{\phi}_1 - \frac{1}{2} l_3 \cdot \sin \phi_1 \cdot \ddot{\phi}_1 - \\ & - \frac{1}{2} l_3 \cdot \cos \phi_1 \cdot \dot{\phi}_1^2 - \frac{1}{2} l_3 \cdot \sin \phi_1 \cdot \ddot{\phi}_1 \\ \ddot{y}_{G_1} &= \ddot{y}_E + \frac{1}{2} \ddot{l}_3 \cdot \sin \phi_1 + \frac{1}{2} \dot{l}_3 \cdot \cos \phi_1 \cdot \dot{\phi}_1 + \frac{1}{2} l_3 \cdot \cos \phi_1 \cdot \ddot{\phi}_1 - \\ & - \frac{1}{2} l_3 \cdot \sin \phi_1 \cdot \dot{\phi}_1^2 + \frac{1}{2} l_3 \cdot \cos \phi_1 \cdot \ddot{\phi}_1 \end{aligned} \right. \quad (17)$$

$$\left\{ \begin{aligned} x_G &= x_I - 2a \cdot \cos \phi_6 & \dot{x}_G &= \dot{x}_I + 2a \cdot \sin \phi_6 \cdot \dot{\phi}_6 \\ y_G &= y_I - 2a \cdot \sin \phi_6 & \dot{y}_G &= \dot{y}_I - 2a \cdot \cos \phi_6 \cdot \dot{\phi}_6 \\ \ddot{x}_G &= \ddot{x}_I + 2a \cdot \cos \phi_6 \cdot \dot{\phi}_6^2 + 2a \cdot \sin \phi_6 \cdot \ddot{\phi}_6 \\ \ddot{y}_G &= \ddot{y}_I + 2a \cdot \sin \phi_6 \cdot \dot{\phi}_6^2 - 2a \cdot \cos \phi_6 \cdot \ddot{\phi}_6 \end{aligned} \right. \quad (18)$$

$$\left\{ \begin{aligned} x_H &\equiv x_{G_6} = x_I - a \cdot \cos \phi_6 & \dot{x}_H &= \dot{x}_I + a \cdot \sin \phi_6 \cdot \dot{\phi}_6 \\ y_H &\equiv y_{G_6} = y_I - a \cdot \sin \phi_6 & \dot{y}_H &= \dot{y}_I - a \cdot \cos \phi_6 \cdot \dot{\phi}_6 \\ \ddot{x}_H &= \ddot{x}_I + a \cdot \cos \phi_6 \cdot \dot{\phi}_6^2 + a \cdot \sin \phi_6 \cdot \ddot{\phi}_6 \\ \ddot{y}_H &= \ddot{y}_I + a \cdot \sin \phi_6 \cdot \dot{\phi}_6^2 - a \cdot \cos \phi_6 \cdot \ddot{\phi}_6 \end{aligned} \right. \quad (19)$$

$$\left\{ \begin{aligned} x_{G_7} &= x_G + s_7 \cdot \cos \phi & \dot{x}_{G_7} &= \dot{x}_G \left\{ \begin{aligned} \ddot{x}_{G_7} &= \ddot{x}_G \\ \ddot{y}_{G_7} &= \ddot{y}_G \end{aligned} \right. \\ y_{G_7} &= y_G + s_7 \cdot \sin \phi & \dot{y}_{G_7} &= \dot{y}_G \end{aligned} \right. \quad (20)$$

$$\left\{ \begin{aligned} x_M &= x_G + f \cdot \cos(\phi + \theta) & \dot{x}_M &= \dot{x}_G \left\{ \begin{aligned} \ddot{x}_M &= \ddot{x}_G \\ \ddot{y}_M &= \ddot{y}_G \end{aligned} \right. \\ y_M &= y_G + f \cdot \sin(\phi + \theta) & \dot{y}_M &= \dot{y}_G \end{aligned} \right. \quad (21)$$

## Results

### Forces of the Main Mechanism

The lifting mechanism consists of several parts including linkages, hydraulic drives and motion pairs. Hydraulic drives are the lifting hydraulic cylinder, the buffer hydraulic cylinder and the leaning hydraulic cylinder, which have been individually denoted as c1, c2 and c3. In lifting process, the cylinder c1 controls the vertical movement of work piece through inputting lifting signal.

At the same time, the cylinders c2 and c3 are completely closed. While cylinder c2 is performing horizontal movement, c1 and c3 cylinders are closed. In the same way, when the cylinder c3 realizes leaning movement by inputting leaning signal in leaning condition, the cylinders c1 and c2 are closed.

The forces acting in the mechanism have been determined in this study from the knowledge of the solutions of the system kinematics.

The forces diagram reported in Fig. 4 shows the behavior of a typical forging manipulator, illustrating the basic motions in operation process: Advancement, motion of the tong and buffering.

All the external forces acting on the mechanism, namely, the inertia forces, gravitational forces and the force exerted by the weight of the cast part should be first evaluated, then all the forces from couplers can be calculated.

The instant forces (acting at a certain moment on the mechanism) can be determined in the forces study of a mechanism. The solution is based on the kinematic scheme of the mechanism loaded with all the forces acting on it (Fig. 4). Some forces, such as the external forces, are already known, others, such as those from the couplers, have to be determined.

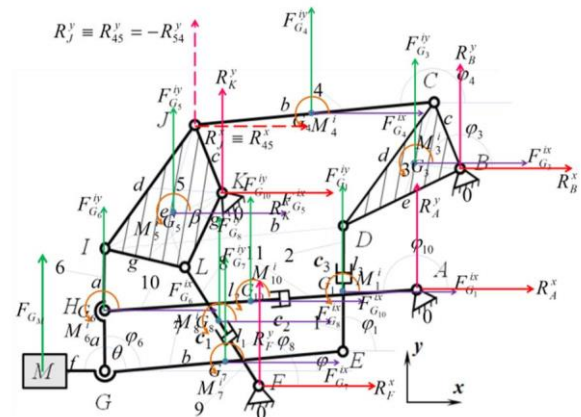


Fig. 4. The forces schema of the main mechanism

In the following step 1 the external forces, namely the forces of inertia and gravitation, are calculated from system (22):

$$\left\{ \begin{array}{l} F_{G_1}^{ix} = -m_{12} \cdot \ddot{x}_{G_1} \\ F_{G_1}^{iy} = -m_{12} \cdot \ddot{y}_{G_1} - m_{12} \cdot g \\ M_1^i = -J_{G_1} \cdot \ddot{\phi}_1 \end{array} \right. \left\{ \begin{array}{l} F_{G_3}^{ix} = -m_3 \cdot \ddot{x}_{G_3} \\ F_{G_3}^{iy} = -m_3 \cdot \ddot{y}_{G_3} - m_3 \cdot g \\ M_3^i = -J_{G_3} \cdot \ddot{\phi}_3 \end{array} \right. \\
 \left\{ \begin{array}{l} F_{G_4}^{ix} = -m_4 \cdot \ddot{x}_{G_4} \\ F_{G_4}^{iy} = -m_4 \cdot \ddot{y}_{G_4} - m_4 \cdot g \\ M_4^i = -J_{G_4} \cdot \ddot{\phi}_4 = 0 \end{array} \right. \left\{ \begin{array}{l} F_{G_5}^{ix} = -m_5 \cdot \ddot{x}_{G_5} \\ F_{G_5}^{iy} = -m_5 \cdot \ddot{y}_{G_5} - m_5 \cdot g \\ M_5^i = -J_{G_5} \cdot \ddot{\phi}_5 \end{array} \right. \\
 \left\{ \begin{array}{l} F_{G_6}^{ix} = -m_6 \cdot \ddot{x}_{G_6} = -m_6 \cdot \ddot{x}_H \\ F_{G_6}^{iy} = -m_6 \cdot \ddot{y}_H - m_6 \cdot g \\ M_6^i = -J_H \cdot \ddot{\phi}_6 \end{array} \right. \left\{ \begin{array}{l} F_{G_7}^{ix} = -m_7 \cdot \ddot{x}_{G_7} \\ F_{G_7}^{iy} = -m_7 \cdot \ddot{y}_{G_7} - m_7 \cdot g \\ M_7^i = -J_{G_7} \cdot \ddot{\phi}_7 \end{array} \right. \\
 \left\{ \begin{array}{l} F_M^{ix} = -M \cdot \ddot{x}_M \\ F_M^{iy} = -M \cdot \ddot{y}_M - M \cdot g \\ M_M^i = -J_M \cdot \ddot{\phi} \end{array} \right. \left\{ \begin{array}{l} F_{G_8}^{ix} = -m_{89} \cdot \ddot{x}_{G_8} \\ F_{G_8}^{iy} = -m_{89} \cdot \ddot{y}_{G_8} - m_{89} \cdot g \\ M_8^i = -J_{G_8} \cdot \ddot{\phi}_8 \end{array} \right. \\
 \left\{ \begin{array}{l} F_{G_{10}}^{ix} = -m_{10,11} \cdot \ddot{x}_{G_{10}} \\ F_{G_{10}}^{iy} = -m_{10,11} \cdot \ddot{y}_{G_{10}} - m_{10,11} \cdot g \\ M_{10}^i = -J_{G_{10,11}} \cdot \ddot{\phi}_{10} \end{array} \right. \left\{ \begin{array}{l} J_{G_i} = \frac{1}{12} m_i \cdot l_i \end{array} \right. \quad (22)$$

Now we can consider three separate systems (23-25) that are needed to evaluate the reactions of motor couplings dyad (indicated as 7, 1 and 2 in Fig. 5):

$$\left\{ \begin{array}{l} \sum M_D^{(7,1)} = 0 \Rightarrow F_M^{ix} \cdot (y_D - y_M) - F_M^{iy} \cdot (x_D - x_M) + M_M^i + \\ + R_G^x \cdot (y_D - y_G) - R_G^y \cdot (x_D - x_G) + F_{G_7}^{ix} \cdot (y_D - y_{G_7}) - \\ - F_{G_7}^{iy} \cdot (x_D - x_{G_7}) + M_7^i + F_{G_1}^{ix} \cdot (y_D - y_{G_1}) - F_{G_1}^{iy} \cdot (x_D - x_{G_1}) + M_1^i = 0 \\ \sum M_E^{(7)} = 0 \Rightarrow F_M^{ix} \cdot (y_E - y_M) - F_M^{iy} \cdot (x_E - x_M) + M_M^i + \\ + R_G^x \cdot (y_E - y_G) - R_G^y \cdot (x_E - x_G) + F_{G_7}^{ix} \cdot (y_E - y_{G_7}) - \\ - F_{G_7}^{iy} \cdot (x_E - x_{G_7}) + M_7^i = 0 \\ \left\{ \begin{array}{l} a_{11} = y_D - y_G; a_{12} = x_G - x_D \\ a_1 = (y_M - y_D) F_M^{ix} + (x_D - x_M) F_M^{iy} - M_M^i + \\ + (y_{G_7} - y_D) F_{G_7}^{ix} + (x_D - x_{G_7}) F_{G_7}^{iy} - M_7^i + \\ + (y_{G_1} - y_D) F_{G_1}^{ix} + (x_D - x_{G_1}) F_{G_1}^{iy} - M_1^i \end{array} \right. \\ \left\{ \begin{array}{l} a_{21} = y_E - y_G; a_{22} = x_G - x_E; a_2 = (y_M - y_E) F_M^{ix} + (x_E - x_M) F_M^{iy} - \\ - M_M^i + (y_{G_7} - y_E) F_{G_7}^{ix} + (x_E - x_{G_7}) F_{G_7}^{iy} - M_7^i \end{array} \right. \\ \Delta = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11} \cdot a_{22} - a_{12} \cdot a_{21}; \Delta_x = \begin{vmatrix} a_1 & a_{12} \\ a_2 & a_{22} \end{vmatrix} = a_1 \cdot a_{22} - a_2 \cdot a_{12} \\ \Delta_y = \begin{vmatrix} a_{11} & a_1 \\ a_{21} & a_2 \end{vmatrix} = a_2 \cdot a_{11} - a_1 \cdot a_{21}; R_G^x \equiv R_G^x = \frac{\Delta_x}{\Delta}; R_G^y \equiv R_G^y = \frac{\Delta_y}{\Delta} \end{array} \quad (23)$$

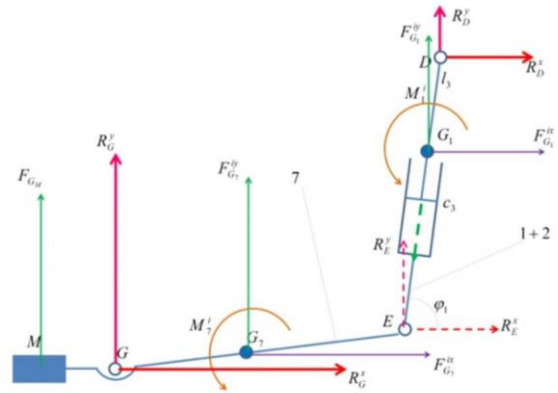


Fig. 5. The forces schema of the dyad (7,1 and 2)

$$\left\{ \begin{array}{l} \sum F_x^{(7,1)} = 0 \Rightarrow R_D^x + F_{G_1}^{ix} + F_{G_7}^{ix} + R_G^x + F_M^{ix} = 0 \Rightarrow \\ \Rightarrow R_D^x = -F_{G_1}^{ix} - F_{G_7}^{ix} - R_G^x - F_M^{ix} \\ \sum F_y^{(7,1)} = 0 \Rightarrow R_D^y + F_{G_1}^{iy} + F_{G_7}^{iy} + R_G^y + F_M^{iy} = 0 \Rightarrow \\ \Rightarrow R_D^y = -F_{G_1}^{iy} - F_{G_7}^{iy} - R_G^y - F_M^{iy} \end{array} \right. \quad (24)$$

$$\left\{ \begin{array}{l} \sum F_x^{(1)} = 0 \Rightarrow R_D^x + F_{G_1}^{ix} + R_E^x = 0 \Rightarrow R_E^x = -F_{G_1}^{ix} - R_D^x \\ \sum F_y^{(1)} = 0 \Rightarrow R_D^y + F_{G_1}^{iy} + R_E^y = 0 \Rightarrow R_E^y = -F_{G_1}^{iy} - R_D^y \end{array} \right. \quad (25)$$

We can then evaluate from the solution of systems (26-28) the next motor dyad elements (reported as 6, 10 and 11 in Fig. 6):

$$\left\{ \begin{array}{l} \sum M_I^{(6,10)} = 0 \Rightarrow R_A^x \cdot (y_I - y_A) + R_A^y \cdot (x_A - x_I) \\ + F_{G_{10}}^{ix} \cdot (y_I - y_{G_{10}}) + \\ + F_{G_{10}}^{iy} \cdot (x_{G_{10}} - x_I) + M_{10}^i + F_{G_6}^{ix} \cdot (y_I - y_H) \\ + F_{G_6}^{iy} \cdot (x_H - x_I) + M_6^i + \\ + (-R_G^x) \cdot (y_I - y_G) + (-R_G^y) \cdot (x_G - x_I) = 0 \\ \sum M_H^{(10)} = 0 \Rightarrow R_A^x \cdot (y_H - y_A) + R_A^y \cdot (x_A - x_H) \\ + F_{G_{10}}^{ix} \cdot (y_H - y_{G_{10}}) + F_{G_{10}}^{iy} \cdot (x_{G_{10}} - x_H) + M_{10}^i = 0 \\ \left\{ \begin{array}{l} b_{11} = y_I - y_A; b_{12} = x_A - x_I \\ b_1 = (y_{G_{10}} - y_I) F_{G_{10}}^{ix} + (x_I - x_{G_{10}}) F_{G_{10}}^{iy} - \\ - M_{10}^i + (y_H - y_I) F_{G_6}^{ix} + (x_I - x_H) F_{G_6}^{iy} - \\ - M_6^i + (y_I - y_G) R_G^x + (x_G - x_I) R_G^y \end{array} \right. \\ \left\{ \begin{array}{l} b_{21} = y_H - y_A; b_{22} = x_A - x_H; \\ b_2 = (y_{G_{10}} - y_H) F_{G_{10}}^{ix} + (x_H - x_{G_{10}}) F_{G_{10}}^{iy} - M_{10}^i \end{array} \right. \\ \delta = \begin{vmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{vmatrix} = b_{11} \cdot b_{22} - b_{12} \cdot b_{21}; \delta_x = \begin{vmatrix} b_1 & b_{12} \\ b_2 & b_{22} \end{vmatrix} = b_1 \cdot b_{22} - b_2 \cdot b_{12} \\ \delta_y = \begin{vmatrix} b_{11} & b_1 \\ b_{21} & b_2 \end{vmatrix} = b_2 \cdot b_{11} - b_1 \cdot b_{21}; R_A^x = \frac{\delta_x}{\delta}; R_A^y = \frac{\delta_y}{\delta} \end{array} \right. \quad (26)$$

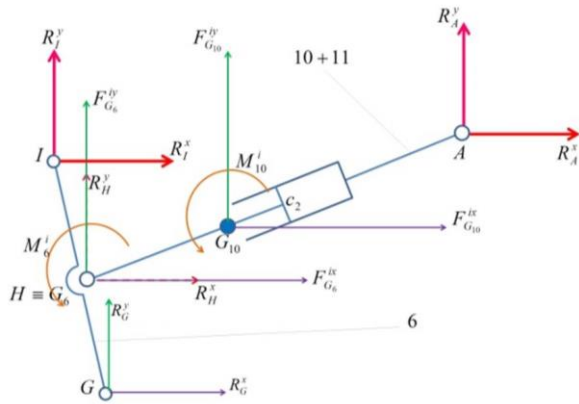


Fig. 6. The forces scheme of the dyad (6,10-11)

$$\begin{cases} \sum F_x^{(6,10)} = 0 - R_I^x + F_{G_6}^{ix} - R_G^x + F_{G_{10}}^{ix} + R_A^x = 0 \Rightarrow \\ \Rightarrow R_I^x = F_{G_6}^{ix} - R_G^x + F_{G_{10}}^{ix} + R_A^x \\ \sum F_y^{(6,10)} = 0 - R_I^y + F_{G_6}^{iy} - R_G^y + F_{G_{10}}^{iy} + R_A^y = 0 \Rightarrow \\ \Rightarrow R_I^y = F_{G_6}^{iy} - R_G^y + F_{G_{10}}^{iy} + R_A^y \end{cases} \quad (27)$$

$$\begin{cases} \sum F_x^{(10)} = 0 R_H^x + F_{G_{10}}^{ix} + R_A^x = 0 \Rightarrow \\ \Rightarrow R_H^x = -F_{G_{10}}^{ix} - R_A^x \\ \sum F_y^{(10)} = 0 R_H^y + F_{G_{10}}^{iy} + R_A^y = 0 \Rightarrow \\ \Rightarrow R_H^y = -F_{G_{10}}^{iy} - R_A^y \end{cases} \quad (28)$$

The next calculations to the dyad (single, not driven, comprising the elements 3, 4), can be seen in the systems (29-31) Fig. 7:

$$\begin{cases} \sum M_B^{(3,4)} = 0 \Rightarrow (-R_J^x) \cdot (y_B - y_J) + (-R_J^y) \cdot (x_J - x_B) + \\ + F_{G_4}^{ix} \cdot (y_B - y_{G_4}) + F_{G_4}^{iy} \cdot (x_{G_4} - x_B) + M_4^i + F_{G_3}^{ix} \cdot (y_B - y_{G_3}) + \\ + F_{G_3}^{iy} \cdot (x_{G_3} - x_B) + M_3^i + (-R_D^x) \cdot (y_B - y_D) + (-R_D^y) \cdot (x_D - x_B) = 0 \\ \sum M_C^{(4)} = 0 \Rightarrow (-R_J^x) \cdot (y_C - y_J) + (-R_J^y) \cdot (x_J - x_C) + \\ + F_{G_4}^{ix} \cdot (y_C - y_{G_4}) + F_{G_4}^{iy} \cdot (x_{G_4} - x_C) + M_4^i = 0 \\ \begin{cases} c_{11} = y_J - y_B; c_{12} = x_B - x_J \\ c_1 = (y_{G_4} - y_B) F_{G_4}^{ix} + (x_B - x_{G_4}) F_{G_4}^{iy} - \\ - M_4^i + (y_{G_3} - y_B) F_{G_3}^{ix} + (x_B - x_{G_3}) F_{G_3}^{iy} - \\ - M_3^i + (y_B - y_D) R_D^x + (x_D - x_B) R_D^y \end{cases} \\ \begin{cases} c_{21} = y_J - y_C; c_{22} = x_C - x_J; \\ c_2 = (y_{G_4} - y_C) F_{G_4}^{ix} + (x_C - x_{G_4}) F_{G_4}^{iy} - M_4^i \end{cases} \\ \lambda = \begin{vmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{vmatrix} = c_{11} \cdot c_{22} - c_{12} \cdot c_{21}; \lambda_x = \begin{vmatrix} c_1 & c_{12} \\ c_2 & c_{22} \end{vmatrix} = c_1 \cdot c_{22} - c_2 \cdot c_{12} \\ \lambda_y = \begin{vmatrix} c_{11} & c_1 \\ c_{21} & c_2 \end{vmatrix} = c_2 \cdot c_{11} - c_1 \cdot c_{21}; R_J^x = \frac{\lambda_x}{\lambda}; R_J^y = \frac{\lambda_y}{\lambda} \end{cases} \quad (29)$$

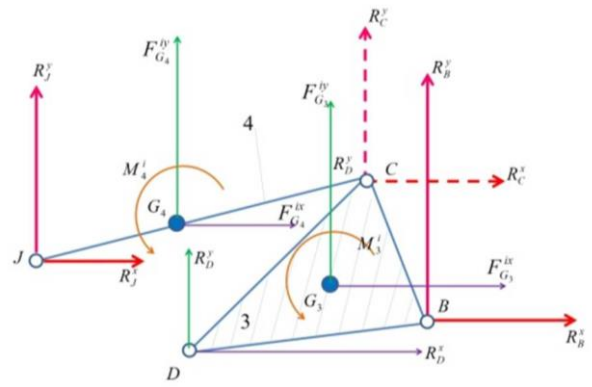


Fig. 7. The forces scheme of the dyad 3,4

$$\begin{cases} \sum F_x^{(3,4)} = 0 R_B^x + F_{G_3}^{ix} + F_{G_4}^{ix} - R_J^x - R_D^x = 0 \Rightarrow \\ \Rightarrow R_B^x = R_J^x + R_D^x - F_{G_3}^{ix} - F_{G_4}^{ix} \\ \sum F_y^{(3,4)} = 0 R_B^y + F_{G_3}^{iy} + F_{G_4}^{iy} - R_J^y - R_D^y = 0 \Rightarrow \\ \Rightarrow R_B^y = R_J^y + R_D^y - F_{G_3}^{iy} - F_{G_4}^{iy} \end{cases} \quad (30)$$

$$\begin{cases} \sum F_x^{(4)} = 0 R_C^x + F_{G_4}^{ix} - R_J^x = 0 \Rightarrow \\ \Rightarrow R_C^x = R_J^x - F_{G_4}^{ix} \\ \sum F_y^{(4)} = 0 R_C^y + F_{G_4}^{iy} - R_J^y = 0 \Rightarrow \\ \Rightarrow R_C^y = R_J^y - F_{G_4}^{iy} \end{cases} \quad (31)$$

The calculation continues with the next motor dyad, which is composed by the elements 5, 8 and 9 (Fig. 8), solving the systems (32-34):

$$\begin{cases} \sum M_K^{(5,8)} = 0 \Rightarrow R_F^x \cdot (y_K - y_F) + R_F^y \cdot (x_F - x_K) + F_{G_8}^{ix} \cdot (y_K - y_{G_8}) + \\ + F_{G_8}^{iy} \cdot (x_{G_8} - x_K) + M_8^i + F_{G_5}^{ix} \cdot (y_K - y_{G_5}) + F_{G_5}^{iy} \cdot (x_{G_5} - x_K) + M_5^i + \\ + R_I^x \cdot (y_K - y_I) + R_I^y \cdot (x_I - x_K) + R_J^x \cdot (y_K - y_J) + R_J^y \cdot (x_J - x_K) = 0 \\ \sum M_L^{(8)} = 0 \Rightarrow R_F^x \cdot (y_L - y_F) + R_F^y \cdot (x_F - x_L) + F_{G_8}^{ix} \cdot (y_L - y_{G_8}) + \\ + F_{G_8}^{iy} \cdot (x_{G_8} - x_L) + M_8^i = 0 \\ \begin{cases} d_{11} = y_K - y_F; d_{12} = x_F - x_K \\ d_1 = (y_{G_8} - y_K) F_{G_8}^{ix} + (x_K - x_{G_8}) F_{G_8}^{iy} - \\ - M_8^i + (y_{G_5} - y_K) F_{G_5}^{ix} + (x_K - x_{G_5}) F_{G_5}^{iy} - \\ - M_5^i + (y_I - y_K) R_I^x + (x_K - x_I) R_I^y + \\ + (y_J - y_K) R_J^x + (x_K - x_J) R_J^y \end{cases} \\ \begin{cases} d_{21} = y_L - y_F; d_{22} = x_F - x_L; \\ d_2 = (y_{G_8} - y_L) F_{G_8}^{ix} + (x_L - x_{G_8}) F_{G_8}^{iy} - M_8^i \end{cases} \\ \Phi = \begin{vmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{vmatrix} = d_{11} \cdot d_{22} - d_{12} \cdot d_{21}; \Phi_x = \begin{vmatrix} d_1 & d_{12} \\ d_2 & d_{22} \end{vmatrix} = d_1 \cdot d_{22} - d_2 \cdot d_{12} \\ \Phi_y = \begin{vmatrix} d_{11} & d_1 \\ d_{21} & d_2 \end{vmatrix} = d_2 \cdot d_{11} - d_1 \cdot d_{21}; R_F^x = \frac{\Phi_x}{\Phi}; R_F^y = \frac{\Phi_y}{\Phi} \end{cases} \quad (32)$$

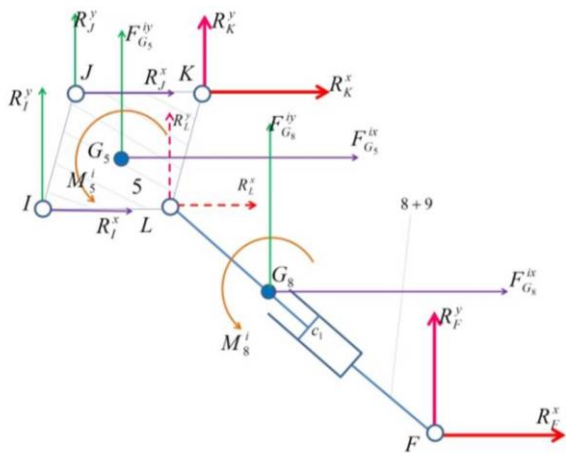


Fig. 8. The forces schema of the dyad (5,8-9)

$$\begin{cases} \sum F_x^{(5,8)} = 0 & R_K^x + R_J^x + R_I^x + R_F^x + F_{G_5}^{ix} + F_{G_8}^{ix} = 0 \Rightarrow \\ \Rightarrow R_K^x = -R_J^x - R_I^x - R_F^x - F_{G_5}^{ix} - F_{G_8}^{ix} \\ \sum F_y^{(5,8)} = 0 & R_K^y + R_J^y + R_I^y + R_F^y + F_{G_5}^{iy} + F_{G_8}^{iy} = 0 \Rightarrow \\ \Rightarrow R_K^y = -R_J^y - R_I^y - R_F^y - F_{G_5}^{iy} - F_{G_8}^{iy} \end{cases} \quad (33)$$

$$\begin{cases} \sum F_x^{(8)} = 0 & R_L^x + F_{G_8}^{ix} + R_F^x = 0 \Rightarrow \\ \Rightarrow R_L^x = -R_F^x - F_{G_8}^{ix} \\ \sum F_y^{(8)} = 0 & R_L^y + F_{G_8}^{iy} + R_F^y = 0 \Rightarrow \\ \Rightarrow R_L^y = -R_F^y - F_{G_8}^{iy} \end{cases} \quad (34)$$

### Driving Forces of the Main Mechanism

Finally, we can determine the three driving forces. Figure 9 reports the engine c1, which comprises the kinematic elements 8 and 9.

Determine motive power  $F_{m1}$  with relations of the system (35); being two relations of calculation may be carried out a check:

$$\begin{cases} \sum F_x^{(8)} = 0 \Rightarrow F_{m1} \cdot \cos \phi_8 + F_{G_8}^{ix} + R_L^x = 0 \Rightarrow F_{m1} = \frac{-F_{G_8}^{ix} - R_L^x}{\cos \phi_8} \\ \sum F_y^{(8)} = 0 \Rightarrow F_{m1} \cdot \sin \phi_8 + F_{G_8}^{iy} + R_L^y = 0 \Rightarrow F_{m1} = \frac{-F_{G_8}^{iy} - R_L^y}{\sin \phi_8} \end{cases} \quad (35)$$

Figure 10 represents the engine c2, which is composed by the kinematic elements 10 and 11, from which we can determine the motive power  $F_{m2}$  using the equations of the system (36):

$$\begin{cases} \sum F_x^{(10)} = 0 \Rightarrow F_{m2} \cdot \cos \phi_{10} + F_{G_{10}}^{ix} + R_H^x = 0 \Rightarrow F_{m2} = \frac{-F_{G_{10}}^{ix} - R_H^x}{\cos \phi_{10}} \\ \sum F_y^{(10)} = 0 \Rightarrow F_{m2} \cdot \sin \phi_{10} + F_{G_{10}}^{iy} + R_H^y = 0 \Rightarrow F_{m2} = \frac{-F_{G_{10}}^{iy} - R_H^y}{\sin \phi_{10}} \end{cases} \quad (36)$$

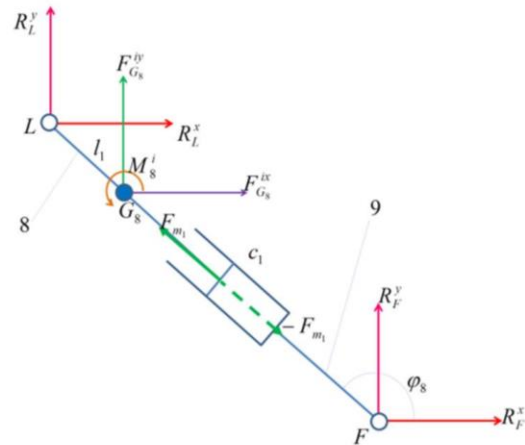


Fig. 9. Forces schema of the motor mechanism c1

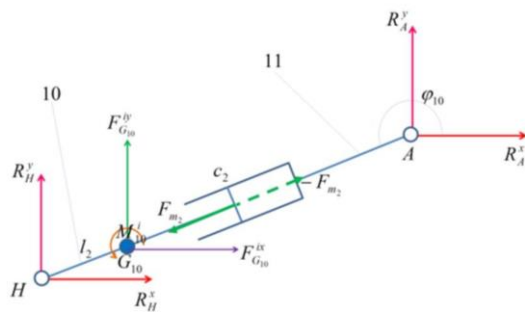


Fig. 10. Forces schema of the motor mechanism c2

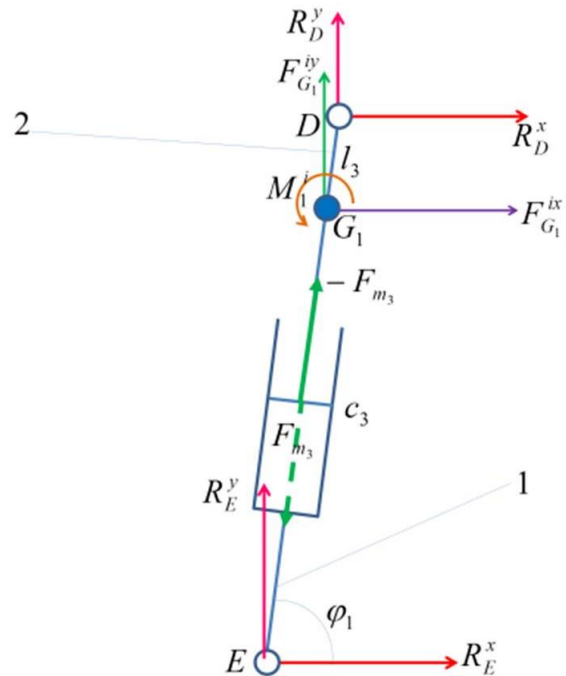


Fig. 11. Forces schema of the motor mechanism c3



Figure 11 represents the engine c3, which is composed by the kinematic elements 1 and 2, from which we determine the motive power  $F_{m3}$  by using the relations of the system (37):

$$\begin{cases} \sum F_x^{(1)} = 0 \Rightarrow -F_{m3} \cdot \cos \phi_1 + F_{G_1}^{ix} + R_E^x = 0 \Rightarrow F_{m3} = \frac{F_{G_1}^{ix} + R_E^x}{\cos \phi_1} \\ \sum F_y^{(1)} = 0 \Rightarrow -F_{m3} \cdot \sin \phi_1 + F_{G_1}^{iy} + R_E^y = 0 \Rightarrow F_{m3} = \frac{F_{G_1}^{iy} + R_E^y}{\sin \phi_1} \end{cases} \quad (37)$$

## Discussion

Since 1961 forging manipulators are used in the manufacturing railway industry. Projects have been continuously improved this technology up to today where we further consider innovations to solve problems of forging processes based on machine experience, safety and economy.

These forging manipulators meet all requirements for modern production machines. Handlers are special connectors designed for fast acting forging presses and tests for innovations are necessary to be able to integrate them with a forging press and to automate the forging process with procedures controlled by means of a computer system.

In addition, by use of a central energy storage device, the total power consumption could be significantly reduced because these batteries cover the energy peaks requirements. This innovation leads into smaller components in terms of capacity (electric motors, pumps) and thereby lower the maintenance costs. The mechanical package consists of several pumps powered engines that are arranged in repetitive system 2,3,4 or more identical units. Thus, manipulator can operate continuously at almost complete full capacity even if one of the units is stopped in case of damage. Thus, the defective unit can be replaced during maintenance shift without the production being halted.

This hydraulic power pack is completely soundproof and all components are finished and systematically arranged to enable instant access for maintenance staff in order to have it quickly serviced.

The drivetrain, which is connected directly to the peeling clamp (clamp device rotation and pliers), pushes the belt to ensure the best accuracy incremental steps while running at maximum acceleration capabilities and low power consumption.

This separation of the masses (e.g., Clamps peeling and displacement unit) imply that a single unit is directly operated, while the main manipulator chassis with connection and powers will automatically provide accelerations and low speeds.

This separation of the masses can be used both in automatic mode but also in manual mode and must be used any time during normal forging. Handling discs and

rings repression during this separation can be hydraulically suspended.

Hydraulic motors, which are hydraulically tensioned using planetary gears and sprockets, respectively offer well-synchronized functions. This mode of moving turns into good report steps to tread with utmost precision, even more so, normal wear and bolts of the gear motor is compensated consistently rack.

Forging ingot profile square and rectangular ingot or for operation with extensions of the arms is essential to use a lateral shift system in parallel to clamps peeling. Especially if you have to forging disks, rings or plates and sleeves, it is needed the use of extension arms. The project combines both requirements without additional design features using individual systems for lateral shift, one in front and the other associated to suspension peeling clamps.

Peeling clamps are made of individual elements such as the clamps themselves, drum and rotating mechanism that are assembled together to create the device.

This system does not require a peeling box and then, all components are quickly accessible for any service maintenance and, besides this, its weight is lower than for a conventional machine equipped with a peeling box.

Jaw clamps are set with a fast interchanging system. The lever clamp is made of forged steel resistant to high temperatures.

Forging manipulator railway will be equipped with a hydraulic radial piston motors integrated and available volume for the motor function and selectable for rotating the clamp function. In manual mode, the speed selection will be made by the operator while, in automatic mode, the speed range selection will be automatically determined by the system.

To have a running system responsible for limited operations, which should not interfere with the work environment, the forging manipulator uses a rigid rack-pinion rail that sits on the floor of the manipulator.

To allow the handler to participate in forging rings, discs and plates, clamps can be attached along with major set of arms extended. These arms will be attached clamps extended key, removing the jaws. These arms can be equipped with either extended clamping peaks as shown below or lower jaw to the tip end.

In order to achieve an optimized relationship between weight and resistance equipment suitable components, especially those that are in constant motion, the system uses FEM analysis to optimize the design of all major components of the manipulator.

Resetting automatic and continuous control of positioning is a basic application for any manipulator himself for forging and care control electric main axes so as to stabilize the ingot during forging automated or semi-automated to integrate belonging forging press. This will be done mainly by the main axis that has controlled position control with the beat of the press.

Overloads, if any, caused by the forging operation will automatically compensate for hydraulic and electric.

GSM handler meets all requirements for a forging plant with forging. It was specifically designed for use with a rapid-action release and has all the facilities necessary for integration with a forging press and forging process automation and to be able to control computerized procedure forging.

The frame is made of welded steel rigid building boards with two wheels in front and two rear wheels, anti-friction bearings running on.

The wheels are made of hardened steel at high temperatures to harden the tread surface, running it with a useful width of 75 mm.

Jaws rotate anti-friction bearings bark.

Opening and closing the jaws grip the cylinder is made differential and trees bell. A hydraulic accumulator located in the clamp circuit assures constant pressure to close the jaws. Squeeze your arms are suitable to accommodate the discharge arms and jaws for insertion without the need to dismantle arm clamps and clamping jaws.

Bark helical supports both horizontal direction but also the vertical direction.

Installing the shell is being designed pendulum so that loading times, which constantly change during forging, do not have effect on shell height.

Running gears are mounted directly on the skin and move the drive-train.

By separating bodies (e.g., Claws and skin are a unit, while the chassis handler with the system of levers and tanks are pulled behind without control most states flexibility), range of motion is applied primarily on the shell, so, large accelerations increment every minute can be achieved. The engine consists of two hydraulic motors and planetary gearbox gears, which due to a special control system ensure a race without playing.

This forging-is the procedure of processing by plastic deformation when warm which consists in changing the shape of a semifinished, due to static and dynamic exercised by the specific equipment, forces which causes the flow of material on different directions under the action of the successive blows or by squeezing.

This forging is done by the creation of a prospectively observed statuses in the volume of material, accompanied by the flow of material on different directions under the action of the successive blows or static.

The nature of the technology forces:

1. Static-Pressing
2. Dynamic-banging

Depending on the nature of the technology and restrictions on the flow of the materials we distinguish two technological process:

1. Forging free, at which the flow of material is free

2. Forging into the mold, at which the flow of material is limited, deformation of making it into a cavity of a tool called the mold

Advantages:

- Are obtained complex parts from a few grams to a few tonnes
- By forging improves the mechanical properties of the parts obtained, which makes the procedure to be used in the processing of the powerful parts requested such as crankshafts, valves, the con rods, gears, etc
- Improves the index of the use of materials
- Conducts a favorable orientation of the fibers to the axis of the efforts

To be forging is a property of technology. By forging materials shall mean those materials and alloys which may be damaged plastic by forging. For example “steels calmed”, copper alloys, aluminum alloys, of magnesium, etc. does not all materials are forging.

The half-finished items for forging can be in the form of bullion, laminates castings.

The processes of forging free are extremely varied, but all represents only the combination of simple operations called basic operations.

To this forging free processing takes place on the vertical, the material being seated usually for a fixed part called “the anvil” or “Mean” and being forced or hit by a Aries, directly or by means of special tools.

The areas in which the shaker comes into contact with the material they are removable, can be used sabote as needed. The main operations that may be carried out by forging free are:

1. Swapping-to increase the dimensions of the orthogonal to the detriment of the longitudinal (length)
2. The tension of the-the reciprocal of the relief (we simple stretch to cards, spreading on the mandrel what is being done to increase the length and the reduction of the outer diameter, smoothing on the mandrel)
3. Drilling
4. Bending
5. Cut
6. Welding
7. Twisting

The machinery used is:

1. Mechanical hammers for forging or free in the mold with single or double effect; the

Mallets transmit suddenly that the material deforms the kinetic energy of the earth located in motion. Their

action is accompanied by noise and mechanical vibration. During the impactor being short, the pressure of deformation does not have time to be up inside the parts.

2. The mills used may be:

- Stack
- The slip
- With crank
- With the crankshaft

The stages of technological process of forging are:

1. The development of the design of the part of the forged
2. The calculation of the half-made
3. Cutting
4. Heating
5. Forging
6. Heat treatment
7. Cleaning
8. Technical inspection of quality

The main elements intended for forging, are:

- Bullion with section round with a diameter of 500 and 600 mm and weights between 2000 and 4000 kg
- Blums with square section or rectangular (with the ratio of less than 2), with the side between  $150 \pm 5$  mm and  $400 \pm 10$  mm, with rounded edges and lengths of 2 ... 6 m, reforging intended
- Billets with section square or round with the side of a maximum of  $350 \pm 6$  mm and with a length of not more than 6 m, reforging intended

The reception of the half-finished products intended for forging will be based on the following documents:

- Newsletter chemical analysis
- Note of weight
- Control bulletin US
- Newsletter for the determination of the temperature of the transition period

The half-finished items intended for forging, will store it in the forge, in the area of the reception, where will weigh and mark with the paint. They will sort according to the following criteria:

- Brand of material
- The lot from which they originate
- Dimensions

### *Warming up with a View to Forging*

The half-finished items intended for forging will rise up from the reception zone using the crane, will be carried and charges in the preheated heating using the handler/extractor.



Fig. 12. Heating of the half-finished products intended for forging

Heating of the half-finished products intended for forging, this is a very important as an incorrect heating will lead to both henceforth behavior plastic deformation and the generation of cracks protection during forging (Fig. 12).

### *The Oven for Heating the TITANIUM ALLOYS*

Electric ovens are used to carrying out the operations of heating ingots and half-finished products from the titanium and alloys of titanium or other non-ferrous metals for forging.

The dimensions of the ingots and forged half-finished products which are the subject of heating:

- Ingots titanium and alloys titanium or other non-ferrous metals having regard section round with diameter  $D = 500; 600; 700\text{mm}$ ; Length  $L_{\text{max}} = 3500\text{mm}$  and the weight of the  $G_{\text{max}} = 5000\text{kg}$
- besides the forged (elements) section round with diameter  $d = 100-350$  mm and the length of the  $L_{\text{max}} = 5000\text{mm}$
- elements forged rectangular section of side  $l = 100-350$  mm ( $100 \times 100-350 \times 350\text{mm}$ ) and the length of the  $L_{\text{max}} = 5000\text{mm}$
- elements with rectangular section thickness  $s = 100-300\text{mm}$ , Side  $l_{\text{max}} = 800\text{mm}$  and a length  $L_{\text{max}} = 3000\text{mm}$

### *Constructive description furnaces*

Electric ovens are type camera with fixed hearth and the door Guillotine type. The surface of the "Vatra Romaneasca" is  $S_v = 15 \text{ m}^2$  and the maximum working temperature  $T_{\text{max}}$  is  $1300^\circ\text{C}$ .

Main subassemblies of:

- The construction of a metallic is made of panels and profile which serve to support the walls and insulation and refractory tubing the combustion

plant. Also includes ladders and platforms for access to the equipment mounted on the oven

- The combustion plant comprises the equipment, both on the route of the air and on the gas produced by the company Elster Kromschroder-Germany
- The supply of natural gas shall be made to the hall. On the rail general gas are mounted also the adjustment items, protection, execution and the fuse
- General rail of the gas supply of the combustion plant the oven is designed for a maximum of 1 bar and has a structure in accordance with European safety EN 746-2 and from 3381

Regulator has into the composition of a valve insulation (type AKT), a filter (type GFK), a valve overpressure safety intended to protect the components of the downstream of the pressure regulator (JSAV type), a pressure regulator (VGBF type), a relief valve overpressure discharge (type VSBV), two valves of protection (type VK-opening/closing fast), pressure switches minimum-up (type DG), pressure gauge (type RFM KFM-) and gas meter (type DM), etc:

- The combustion plant has provided for checking the sealing their valves general protective, in accordance with the rules of the EC
- The air supply shall be made to a ventilator, on the route in question being fitted the adjustment items and protection
- The presence of air in the downstream of the fan assembly is controlled by the pressure switch of the minimum (type DG) and the pressure gauge (type KFM)
- Burners are the flame payment with a length of the flame of max 20 cm and are mounted on the side walls so that the flame does not come into contact with the parts, allowing a superior of the working area

At the same time the flames of the burners forming on the side walls this provides a large surface area of the radiation overheat preventing possible local to electric ovens equipped with burners flame with normal.

- The combustion plant is provided with automatic ignition and flame monitoring for each igniter
- Installation of the exhaust fumes, is made up of the exhaust manifold fumes, flaps with the servomotor, fans of dilution, fan of suction unit and basket of exhaust fumes in hall

The installation allows the simultaneous operation or independence of the furnaces.

The plant is equipped with a system of collection of the particles mounted on the exhaust manifold fumes before the cart.

At the outlet from the oven, the burned gases are diluted with air aspirated taken using the fans of dilution. The suction device is powered via the frequency converter loop through automatic adjustment of the pressure in the oven.

Is located at the rear of the oven, above the collector. Allow the temperature of the burned gases of max 350°C.

Measuring the pressure in the oven is done via a wall socket pressure, located in the side wall of the oven. Next to the pressure take-off is fitted and the pressure transducer.

-Refractory habitual brickwork, is made up of concrete and refractory insulating shelters for the hearth and supports and she awaited of concrete reluctant for burners.

It also includes fiber and ceramic for the door, the walls and the canopy and for the achievement of the seals between the oven, (fireplace door).

To avoid fiber drive ceramic currents the burned gases from the oven and to increase the service life of the fiber, has been provided for the application of a paint coating refractory on the inner surface of the dome, door, bulkheads.

Refractory concretes used are put into 3 layers: A layer of the heat insulating concrete ultra-light, at the mantle of the oven and 2 layers of concrete reluctant dense, of which at from the face of the warm, which is also the layer of the wear is a special concrete. In concretes castings are provided for jointing expands. After pouring the concrete, these ducts shall be filled with ceramic fiber (cardboard or mattress).

The electrical installation and of automation, ensures the operation of electric motors and the operation of the combustion plant. The installation of automation delivers continuous temperature:

- Hardware and software necessary to achieve the programs for the control and the recording of the operating parameters of the oven
- The possibility of operation in manual mode and automatic mode
- Transmission parameters on a central unit to the processing of data (computer) and print data to the printer
- The installation of automation provides the ability to transmit monitored parameters from the computer furnaces in the monitoring network of the recipient

Viewing and the leadership of the process will be carried out in the PC located in the cab of the press or the peHMI on the switch cabinet automation.

These data can be viewed via the internet and work with password for settings from a distance.

The door with the actuator, is made up of: Door itself, spouts and knives, group REDUCER-ENGINE the actuator and the pillars of support.



The oven door is provided with mechanisms of near-away with pneumatic, as well as with the lift-lower electro-mechanical, with geared motor.

The operation of the door mechanisms is ensured with interlocks which allow the lift the door only after its approach on the front of the oven.

Also, interlocks allow you to lower the door only if the door is apart. To ensure a long life for the sealing of the door, the system be carried out with the ceramic fiber.

One of the most important parameters of the heating process is the heating temperature, which together with the heating, considerably influence the behavior to deformation of the plastic titan and its alloys. Such as the holding time is higher, to temperatures greater than 950°C, the average size of kernels increases, so the plasticity is getting worse.

Therefore, high temperature and time than retaining negative influence on the Plasticity of the half-finished is positive by reducing the chemical inhomogeneities due to the fact that the processes of diffusion are very active.

The increase in very vigorous granules occurs at temperatures greater than 1000°C and at temperatures and higher occurs overheating of the half-finished products, leading to the increase in excess grain size decrease of the limits of the grain and to the emergence of discontinuities (cracks) on these limits.

The half-finished items from the titanium and alloys titanium overheated shall be considered to be waste.

When the oven is cold-in this case, the half-finished items are loaded into the oven, heating is lubricated with the oven.

To ensure that the temperature gradient between the center and the suburbia of the product to be as low as possible at the end of the heating, it is necessary that at a temperature of \$ 650-700°C to carry out a level of heating.

The duration of this bearing, will be chosen long enough, in order to obtain a smooth suitable heat. It has been chosen this temperature, because over her oxidation increase after exponential curve.

The following stages of maintenance will be carried out at a temperature of forging.

When the oven is warm-elements will charge directly in the oven heated to a temperature of forging, following that at this temperature to make the maintenance.

The maintenance at a temperature of forging, will comply with the criteria:

- Maintenance should be long enough to be able to achieve thermal homogenization of half-finished
- Maintenance must be sufficiently low to prevent the increase in size and unjustified loss of material by combustion (oxidation). Between these two contradictory criteria must be found. Temperature Ranges for the main alloys titanium are shown in Table 1 and Fig. 13

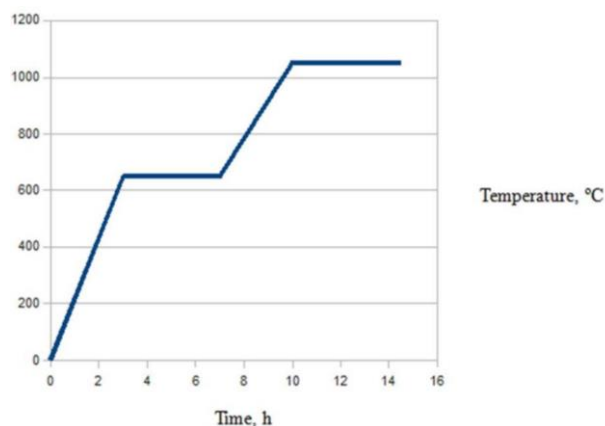


Fig. 13. Chart heating ingots of Ti6Al4V

Table 1. Temperature Ranges for the main alloys titanium

Alloy	Forging starting temperature [°C]	Forging finish temperature[°C]
commercially pure titanium Grad 1-4 (Cf. ASTM)	980	815
Ti5Al2,5Sn	1150	955
Ti8Al1Mo1V	1175	1010
Ti8Mn	980	815
Ti6Al4V	1150	925
Ti7Al4Mo	1175	955
Ti13V11Cr3Al	1175	925

Precautions:

1. Bars will not be placed directly on the hearth oven, but on pedestals, with a view to ensuring a heating as uniformly
2. The diagram of heating system must be strictly adhered to in order to eliminate the above issues (Fig. 13)
3. Gasoil must be carried out with a corresponding yield (injectors must be adjusted correctly to prevent contamination with gas. ingot

Alloys forging starting temperature [°C] Forging finish temperature [°C]:

- Commercially pure titanium
- Grade 4 (cf. ASTM) 980 815
- Ti5Al2,5Sn 1150 955
- Ti8Al1Mo1V 1175 1010
- Ti8Mn 980 815
- Ti6Al4V 1150 925
- Ti7Al4Mo 1175 955
- Ti13V11Cr3Al 1175 925

1. Bars will not be placed directly on the hearth oven, but on support, with a view to ensuring a heating as uniformly

2. Diagram of heating system must be strictly adhered to in order to eliminate the above issues (Table 1)
3. Gasoil must be carried out with a corresponding yield (injectors must be adjusted correctly to prevent contamination with gas. ingot

### Handling Semi Heated

Handling of semi heated can be seen on the Fig. 14.

After performing heating and throughout the forging operation, titanium preforms to be handled carefully because there is a danger doping material. During manipulation observe the following rules:

- During the opening of the furnace necessary blank extraction of titanium, should be minimized to avoid unnecessary energy consumption
- Travel time from oven turntable press 1600 tf be minimized to avoid heat loss of the blank
- Avoid leaving blank warm floor section because it can be contaminated. In cases of accidental residence time on the floor, be minimized

### Forging Beta

The purpose of this operation is a reduction in the cross-section of the semi-finished part and, on the other hand, the destruction of the structure of the casting-in case of ingot and converting it into a new structure (deformation) with improved properties. The reduction of the cross-section is at the same time increasing the length of the blank (Fig. 15).

Due to the fact that at the end of forging beta, it is not required to obtain the mechanical properties and the plastic deformation is carried out under optimum conditions (the ratio of plasticity and resistance to deformation is high) is required at this stage, the material to have a degree of deformation of total high. These results, minimizing the  $\alpha + \beta$  forging, forging that due to low plasticity and high deformation resistance of titanium in this area is more demanding.

Before the start of the forging, is mounted on the hydraulic press of 1600 tf and the corresponding anvils be heated to a temperature between 400 ... 450°C, or by maintaining a heated material between the clips, either by heating them with a burner.

After making the appropriate heating, ingot temperature equal to the temperature began forging furnace heat is extracted from the extractor and deposited on the rotary table. The turntable rotates the ingot, positioning it on the axis of the manipulator. From this position is taken by manipulator and inserted between clips. Forging manipulator will run only from ingot to the head.



Fig. 14. Handling semi heated



Fig. 15. Beta forging



Fig. 16. Manipulating and forging piece reheated

After making a transition, manipulator withdraws submit blank on the turntable, it rotates it in a convenient location extractor is taken and placed in the oven for reheating (Fig. 16):

- Reheating is aimed at bringing the blank at the beginning of forging
- The duration of heating is approx. 30 ... 40 min
- Below is how the resulting beta forging an ingot of Ti6Al4V
- $\varnothing = 580$  mm, L = 3100 mm, G = 3680 kg
- The dimensions of the square section to which the  $\beta$  forging are carried out
- a = 210 mm
- So  $\beta$  forging will go up to 210 square mm, after which it moves to the  $\alpha + \beta$  forging

After completion of each pass, the material will undergo surgery reheating. Temperature of the material after each pass will be at values lower end forging temperature. It will enter into a furnace heated to start forging and will continue to achieve thermal homogenization (Fig. 16):

#### Pass 1

- From round  $\varnothing = 580$  mm, the octagon with an area of 246 176 mm<sup>2</sup>
- L = 3430 mm. Bended C = 1.07
- At this stage, choose a low bended (small strain) as the casting structure is a structure with reduced plasticity. Choosing a higher bended would lead to the appearance of cracks/crevices on the exterior surface. After the destruction of the casting structure-the following passages-bended will have higher values
- Reheating at 1150°C for 20 min keeping

#### Pass 2

- From octagon with an area of 246 176 mm<sup>2</sup> to 450 mm square. L = 4170 mm
- Bended = 1.22
- Reheating at 1150°C for 20 min keeping

#### Pass 3

- From 450 mm square to octagon with an area of 168 750 mm<sup>2</sup>. L = 5000 mm
- Bended = 1.2
- Reheating at 1150°C for 30 min keeping

#### Pass 4

- forging a blank with cutting 1/2 of the half
- From octagon with area of 168 750 mm<sup>2</sup> to 360 mm square
- C = 1.3. L = 6840 mm. L = 3260 mm cutting to square 360 mm, L = 2500 mm respectively, for octagon with an area of 168 750 mm<sup>2</sup>. Debited ingot head
- Reheating at 1150°C for 30 min keeping

#### Pass 4 twice

- From octagon with an area of 168 750 mm<sup>2</sup> to 360 square mm for the remaining 1/2 of the blank after cutting. L = 3260 mm. Debited head bar
- Reheating at 1150°C for 30 min keeping

#### Pass 5

- From 360 mm square to octagon with area 99692mm<sup>2</sup> L = 4238 mm
- Bended = 1.3
- Reheating at 1150°C for 35 min keeping

#### Pass 6

- From octagon with area 99692mm<sup>2</sup> the square of 270 mm. L = 5795 mm. It debiteza in the second semi with L = 2900 mm
- Bended = 1.37
- Reheating at 1150°C for 35 min keeping

#### Pass 7

- From 270 mm square to octagon with surface 56000 mm<sup>2</sup>
- Bended = 1.3. L = 3775 mm
- Reheating at 1050°C for 35 min keeping

#### Pass 8 (last)

- From octagon with surface 56000 mm<sup>2</sup> to 210 mm square
- Bended = 1.27. L = 4793 mm

#### Quality Control

After completing beta forging preforms results will be subject to quality control. During this operation, it will detect surface defects, will mark and defective blanks will be sent to disposal. If the blank surface defects surface, warming it will be sent to forging alpha + beta.

#### Elimination of Surface Defects

This is done by local polishing. The blanks in the state half heated will be carried by the crane, the grinding machine where the polishing surface defects will be removed. Polished area must meet the following relationship:  $d > 2h$ , where:

- d - is the diameter polished surface
- h - the depth of polishing

Failure leads to development of relations wraps during subsequent forging operations. Grinding improper, after which the area presents semi primers for cracks, leading to the production of cracks / crevices in forging alpha + beta.

### Warming to Forging Alpha + Beta

In the case of the heating process the semi-finished titanium and titanium alloys of alpha + beta to forging preforms are transported in the removal of surface defects in the hot oven and loaded at the start of forging. These are held at this temperature for a sufficiently long time to ensure homogenization of the temperature in the entire mass of the preform. Precautions:

- Uneven heating results in improper behavior at the stage of forging following
- Exceeded the set temperature, leading to a poor structure and implicitly discarding material
- Heating at a temperature lower than that set leads to worsening conditions of deformation, thus the appearance of fissures and cracks. To prevent these problems, during heating, the material temperature will be monitored using infrared pyrometer. Forging Temperatures suitable for this step are shown in Table 2

### Forging Alpha + Beta

This forging step is most important, because at its end, are obtained the final products, which must have the mechanical properties and microstructure in accordance with the requirements.

Titanium and its alloys in this temperature range, hardly deforms, the main problem being that the exterior cracks. Factors that may lead to deterioration of the deformation properties of semi-finished products made of titanium, such as in homogeneity, thermal, structural in homogeneities, the already existing cracks, etc., must be reduced to a minimum. Using a low degree of deformation, leading to a poor microstructure and hence the rejection of the material. To minimize these problems take the following measures:

- If during forging alpha + beta blank cracking, will be subject to local polishing operation immediately because existing crack during forging, will develop rapidly, leading to rejection of the material
- Thermal in homogeneities should be detected by measurements. Temperature measurement is done via Infrared pyrometer and if the blank will present on its surface temperature gradient, it will revert to the oven and reheat
- To prevent problems caused by incorrect forging, forging must be a degree of deformation higher degree of deformation characteristic critic alloy. Ti6Al4V alloy for critical degree of deformation is 1.12. In view of this, the degree of deformation imposed on the transition must be greater than 1.2

Table 2. Temperature ranges for the main alloys titanium (Warming to forging alpha + beta).

Alloy	Forging starting temperature [°C]	Forging finish temperature [°C]
Commercially pure Titanium Grad 1-4 (Cf. ASTM)	815	760
Ti5Al2,5Sn	1065	950
Ti8Al1Mo1V	1040	920
Ti8Mn	900	705
Ti6Al4V	955	850
Ti7Al4Mo	1010	860
Ti13V11Cr3Al	1175	925

Table 3. Temperature ranges for the main parameters for the annealing of titanium alloys

Alloy	Temperature [°C]	Holding time, h	Cooling
commercially pure titanium Grad 1-4 (Cf. ASTM)	650-760	0,10-2	air
Ti5Al2,5Sn	720-845	0,16-4	air
Ti8Al1Mo1V	790	1-8	Air or furnace
Ti6Al4V	705-790	1-4	Air or furnace
Ti7Al4Mo	705-790	1-8	air

### Thermal Treatment

Cooled billets will be taken using the crane and cooling bed will be loaded into the heat treatment furnace. The heat treatment usually for billets of titanium and titanium alloys, represents a recrystallization annealing. Following this heat treatment, forging resulting structure at will transform into a new structure, homogenized, which should provide isotropic mechanical properties.

Table 3 presents the main parameters for the annealing of titanium alloys.

### Conclusion

Forging manipulators have become more prevalent in the industry of today. They are used to manipulate objects to be forged. The most common forging manipulators are moving on a railway to have a greater precision and stability. Heavy payload forging manipulators systems are normally characterized by a large load output and a large capacitive load input as well. In this study the authors wish to describe the working principles of new systems made by Dango and Dienenthal. An automatic system machine performs all operations (charging, stoking and distributing work) in accordance with all the requirements of the metallurgical needs. The relationship between outputs and inputs greatly influences the control and the reliability. The great advantages that we have discussed, are related to the decreasing energy consumption (during furnace operation) and the avoidance of damage to the furnace



door, furnace lining, or the electrodes. Furthermore, the operator does not need to stay in the hazardous area near the furnace. Quite often the space on the furnace platform is limited and this requires a more compact and maneuverable vehicles. The compact design of these charging systems, stoking and distributing machines, along with a special lever system, allows these machines to be used in the most limited areas. The driver does not need to leave the control stand for the operations of changing the stoking tool against the charging box. By means of the box, charging material can be brought to specific points in the furnace.

In the situation of tube charging, all the materials may be distributed optimally with the help of the stoking tool.

The same tool can be used for deep stoking, breaking of the slag bridges and opening of gas bubbles, just using the system of levers when the working machine is standing still or during travelling utilizing the mass energy.

The sturdy system machine presented in combination with the powerful drives system guarantees all the needed forces and acceleration. In contrast to solutions with rebuilt fork-lift trucks (known), these new machines provide unlimited view onto the working area, effective protection of the machines hydraulic against the heat radiation of the furnace and clearly decreased maintenance expenses.

These machines use a monorail who allows charging, stoking and distributing from all positions. Additionally the rail leads to a service or parking positions for maintenance work in a protected area.

On request the monorail may be extended so that one machine can work at several furnaces. As an alternative to rail-bound, already known, automatic machines, other machines from the same producer offer a fully-automated variation of the mobile charging and stoking machine. In this study it has been analyzed the general kinematics and forces of the main mechanism of one manipulator.

This work is an original study report of the moving parts and of forces from the basic mechanisms of the proposed systems.

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## Author's Contributions

All the authors contributed equally to prepare, develop and carry out this manuscript.

## Ethics

This article is original and contains unpublished material. Authors declare that are not ethical issues and no conflict of interest that may arise after the publication of this manuscript.

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