Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 33
ISSUE 2
April
2009

Project of a trenchless works tunneling machines ordered construction family

P. Gendarz*, R. Rząsiński
Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: piotr.gendarz@polsl.pl

Received 05.01.2009; published in revised form 01.04.2009

Analysis and modelling

ABSTRACT

Purpose: The water and electricity (etc.) supply is the main problem that big agglomerations meet, therefore the non-excavation works are developed in areas of high buildings density.
Design/methodology/approach: There are many construction solutions of erosion machines that has already been verified in real tests, but the current goal is to develop non – excavation robotized machine. Erosion machines with main dimensions of the tunnels which are: 1600, 2000, 2500, 3150 are design with use of the computer aided methods.
Findings: The result is a modeled in I-DEAS advanced graphical program series of types of the erosion machines with two main designs. The assembly models were analyzed: by system analyze (work simulation of the assembly), by strength analyze (Finite element method) and saved in 2D drawings.
Research limitations/implications: The practical methodology verification of creating the systematic part family was based on the designed erosion machines series of types. There were developed: the algorithmic selection methods of quantitative construction attributes, the construction similarity method of the erosion machines, variant analyzes in the I-DEAS advanced graphical program, program and relational parameterization [3,7,11]. There will be created manufacturing process of the parts, which allows to verify the technology on the CNC machines.
Practical implications: The designed models will be modified and the construction will be consulted with manufacturers and erosion machine users like: OHL ZS a.s. from Brna, Tauber Rohrbau GmbH & Co.KG from Minster. The companies' acceptance will result in practical verification by JUMARPOL company.
Originality/value: The main achievement is the design of a robotized erosion machine to non – excavation works. The designing process was supported by computer aided methods invented on Silesian University of Technology in the I-DEAS advanced graphics program.
Keywords: Engineering design; Constructional design; Series of types

Reference to this paper should be given in the following way:
P. Gendarz, R. Rząsiński, Project of a trenchless works tunneling machines ordered construction family, Journal of Achievements in Materials and Manufacturing Engineering 33/2 (2009) 181-188.

1. Introduction

Construction family orientated process of construction and design varies from the traditional one in inserting a defined set of needs to be satisfied by optimally diversified set of technical means as input [1,15]. General system of ordered construction family of tunneling machines used for trenchless earthworks that corresponds to one Re_o mapping relation, may be defined as: „underground tunneling according to given direction and gradient for power leeds or channels".

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Microtunnel is performed in following stages, Fig. 1 [1, 2]:

- erection of starting and final shaft,
- starting and final shaft construction site should be equipped in controlling and steering room, hydraulic unit, excavated material management system,
- installation of microtunneling drilling machine in the starting shaft,
- microtunnell preformance,
- dismantling of microtunneling drilling machine in the final shaft,
- transportation of equipment and land reclamation.

Figure1 presents the realization of trenchless tunnel drilling.

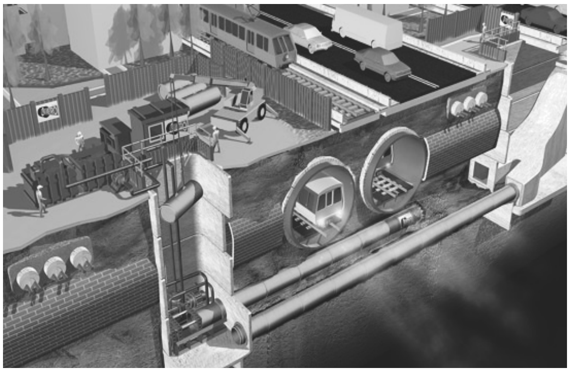


Fig. 1. Microtunneling with fluent excavation material transportation [1]

Ordered construction family of tunneling machines creating process was preceded by analysis of current state. There is a vast variety of constructional solutions for tunneling machines according to the microtunnel creating system. There are tunneling machines with a full cutting shield, with a manipulator accessorized in a ripping head or a special scoop, with simultaneous pipe introduction into the drilled tunnel, Figure 2.

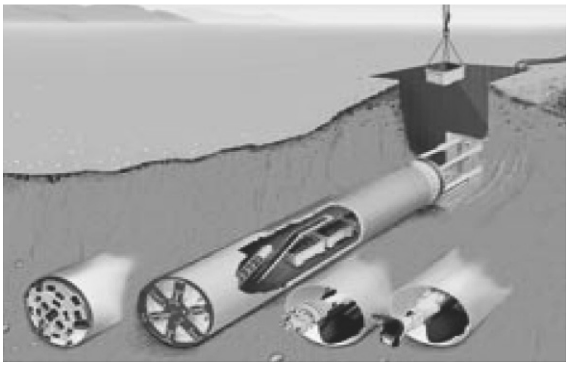


Fig. 2. Types of tunneling machines [2]

The pressing method assumes hydraulic excavation material disposal (benthonit washer) or mechanical one, by: rail cars, belt conveyors, platform augers. When using rinsing transportation, Fig.1, compound of benthonit and excavation materials is pumped into the surface, where the excavation material is removed from the drilling fluid by gravity sedimentation or by separation equipment. While applying the mechanical disposal method, e.g. rail cars, the tunneling process is circular. This is caused by the car filled with material being transported from the end of the mining machine to the starting shaft, where it is being elevated by a crane into the surface and emptied. Such a solution slows down the tunnel drilling process significantly, however one of it's advantages is avoiding the use of expensive machines (for the separation of benthonit and excavating material) or complicated device (introducing the benthonit washer to the ripping head).

The basic criteria to be taken into account while creating a new constructional solution for a tunneling machine in comparison to the existing ones are:

- K1. criteria of tunneling energy reduction,
- K2. introducing trenchless works robotics,
- K3. introducing the biggest possible amount of listed (catalogued) elements and sets.

The initial solution was a construction of a German TAUBER Rohrbau tunneling machine, Figure 3.

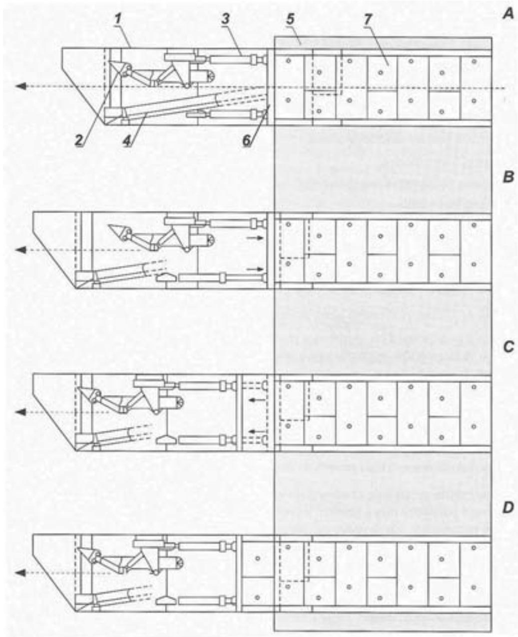


Fig. 3. System illustration of work stages of a technical mean

stage A - digger 2 mines the ground in the forehead and passes it to the belt conveyor 4,
stage B – tunneling pipe 1 is moved inside the new heading using the hydraulic cylinder 3 and bend 6 pushing away from the finished part of the tunnel,
stage C - bend 6 is hidden by the cylinder 3, to expose empty space for building in tubes creating another part of the tunnel,
stage D – after installing the tubes and filling in the empty space 5 in between the external surface of the tunnel and the surrounding ground with filling compound, the cycle is completed and followed by stage A of the following cycle.

Tunneling device, Figure 4.Three-piece MEYER pipes are assembled and introduced after the tunneling device, Figure 5.

Fig. 4. TAUBER tunneling device

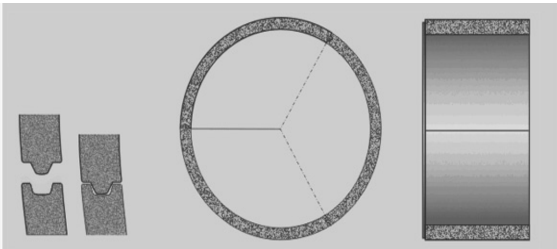


Fig. 5. MEYER tubes

2. Typical features value limitation and ordering

Justified variety of construction family is caused by diversity of needs of defined technical means class [5,6,13,14]. Such a diversity formally enters constructional-designers assumption set identified by characteristic features values, mainly the family construction parameters [3,4,5,8,12]. In the tunneling machines family construction basic parameter is the drilled tunnel's diameter. On the basis of the analysis of Tauber trenchless earthworks needs in Poland unified diameters of drilled tunnels have been defined as follows: D= 1000, 1200, 1600, 2000, 2500, 3150 [mm].

The diameter of tunneling corresponds to the external tube's diameter and is strictly related to the head's diameter. Therefore it has the biggest influence on the characteristic features of the future tunneling machine.

Basing on the prepared programme tunneling machine's dependent parameters such as vertical ground pressure power F_V, horizontal power of the pressing tunneling device - F_H, head's maximum cutting torque M_S for the most inconvenient ground structures, device's relocating speed, tunneling machine's efficiency were assigned.

Tunneling device parameters relations are shown in Table 1.

Table 1.
Tunneling device parameters relations

Tunneling diameter [m]	Head's diameter [m]	Ground pressure on the head (vertical)	Pressure power (horizontal) [kN]	Head's cutting torque [kNm]
1.0	1.4	36.24	422.03	16.16
1.2	1.65	44.07	652.65	26.45
1.6	2.1	55.04	1009.67	47.1
2.0	2.5	67.59	1273.11	81.39
2.5	3.1	83.27	1875.43	143.59
3.15	3.65	103.67	3097.94	263.4

Defined parameters are the basis for the catalogued constructions and further elements constructing choice.

3. Tunneling machines typical constructional forms creating

Variety of qualitative constructional features of a construction family is enclosed in two types of variant construction family structures: system and variant [3,7,9,10,11]. System structure defines elements of technical mean's priorities distinguishing the following construction forms: sets, subsets, elements and their parts, resulting from the priorities structure inside the conjugation and conversion relation system Re^{ozpec}. Relations characterized by the lowest priorities structure and representing the whole spectrum of constructional possibilities for a family of constructions are called isomorphous relations. Variant structure defines variety of constructional possibilities for hierarchically ordered relations. Basing on the system structure of the tunneling device described by Re^z relation and adopted set of criteria; the following tunneling machine sets were defined:

Re^n - ground mining for the transportation purposes $\rightarrow$ mining equipment,
Re^r - performance of the mining device movement $\rightarrow$ robot,
Re^u - relocation of the tunneling machine $\rightarrow$ tunneling machine's to-movement system,
Re^w - shaping a ground opening $\rightarrow$ head's rotation set,
Re^t - transportation of the excavated material from the forehead $\rightarrow$ belt conveyor,
Re^a - transportation of the excavated material into the starting shaft $\rightarrow$ rail car,
Re^m - tubes assembly $\rightarrow$ tubes assembly robot,
Re^l - rail cars and tubes assembly robot relocation $\rightarrow$ engine.

3.1. Mining device

Basic mining devices are heads and scoops. There is a vast variety of construction, enlarged by own ideas. The area of possible construction solutions and prepared set of criteria became the basis for elaborating two constructional solutions for tools R_1^n and R_2^n, Figure 6.

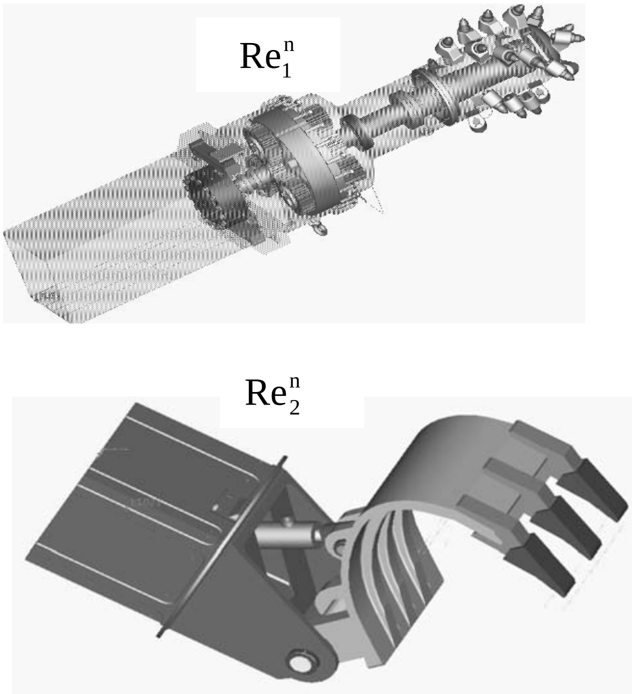


Fig. 6. Constructional solutions for mining devices

Constructional solution R_1^n is equipped in a lengthwise mining ripping head performing rotational movement. This construction was based on Erkat, Tramac and Remag heads. System structure of the tool as follows:

R_1^{n1} - transformation of hydraulic liquid energy into mechanical energy → Rexrot, type A2FE hydraulic engine,

R_1^{n2} - transformation of mechanical energy → three-pass gear,

R_1^{n3} - torque transfer → bearing system drive shaft,

R_1^{n4} - torque transfer from the shaft to the ripping head → Peter type PSV frictional expanding rings,

R_1^{n5} - ground mining → head.

Head's system structure is as follows:

R_1^{n51} - torque and mining load transfer → head's body,

R_1^{n52} - machining tools attachment → tool's holder,

R_1^{n53} - ground machining → rotational tangential knives,

R_1^{n54} - maintaining the knife in its holder → cotter pins.

Constructional solution R_2^n is equipped in a scoop-shaped mining tool. It can be alternatively placed on a robot's arm and is clay- and sand-orientated.

3.2. Performance of the mining device movement

The following paper tends to analyze the use of a vast spectrum of various kinematics-structure robots. Gemotec, Gimatic, Güdel modular robots systems were used. Fig. 7. shows a robot built basing on the Güdel modular system.

Robot is kinematics-structured $\{X_R, C_R, B_R, X_L\}$. Working space is spherical.

X_R - lenghtwise movement, regional, along with X axis → performed by a hydraulic cylinder moving the car on the running track,

A_R - rotational movement, regional, along with Z axis → performed by two cylinder moving the robot's head on the arm. The robot's head is attached by a 4-point Franke, type LEL bearing,

B_R - rotational movement, regional, along with Y axis → performed by cylinder moving the arm. The arm is attached to the rolling bearings,

X_L - lenghtwise movement, local, along with X axis → performed by an inside-arm cylinder, the forearm is run inside the robot's arm by the THK type Flat Roller linear bearing.

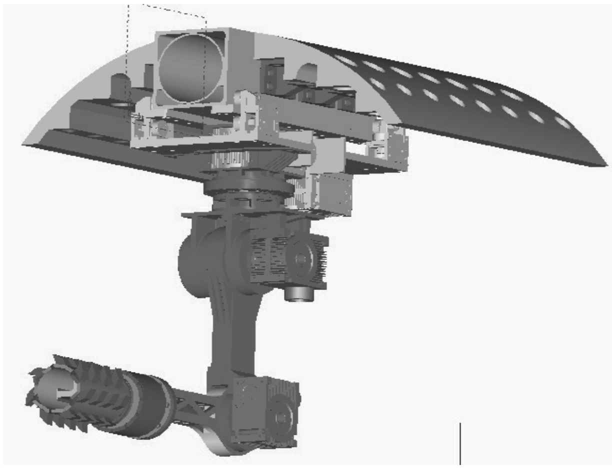


Fig. 7. Model of a robot built on the basis of the Güdel modular system

However, own robot projects were used, what resulted in the following constructional solution, Figure 8.

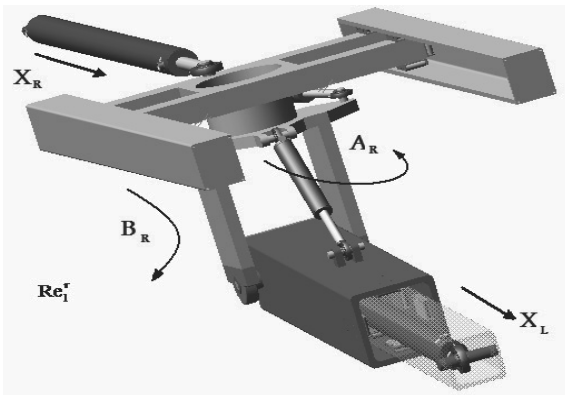


Fig. 8. Model of a trenchless earthworks robot

3.3. Relocation of the tunneling machine

In trenchelss technologies it is common to relocate the tunneling machine by, Figure 9:

- relocating the tubes along with the tunneling machine resting the bearings on the starting shaft (significant energy losses and a threat of damaging the tubes, it requires the use of benthonit liquid to minimize the resistance of transfer),
- relocating the tunneling machine resting the bearings on the last installed tube (which clamps the tubes, however requires delivery and assembly directly after the tunneling machine, what prolongs the entire process).

Basing on the set of criteria we have chosen another technology, applying four bearings attached to the tunneling machine's pipe and resistant rings equipped in a rubber insert, Figure 9. The bearings were chosen according to our own modular system of hydraulic bearings construction on the basis of the required horizontal power F_H.

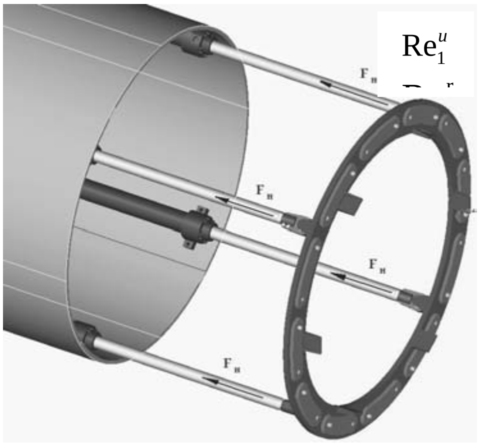


Fig. 9. To-motion unit

3.4. Shaping a ground opening

Shaping a ground opening, relation Re^w, may be performed in two different ways, Figure 10:

Re_1^w - the tunneling machine's body consists of two pipes, where the external one connected to the device's body performs, with the use of cylinders, incomplete oscillatory rotational movement regarding the internal pipe,

Re_2^w - the head performs full rotational movement. Its bearing is in the device's body.

Both ideas were applied in the project. Re_1^w relation idea contains following relations:

Re_1^{w1} - protecting the drilled tunnel → external body of the tunneling machine,

Re_1^{w2} - internal protection → internal body of the tunneling machine,

Re_1^{w3} - internal body positioning relative to the external one → roller guides, Figure 10,

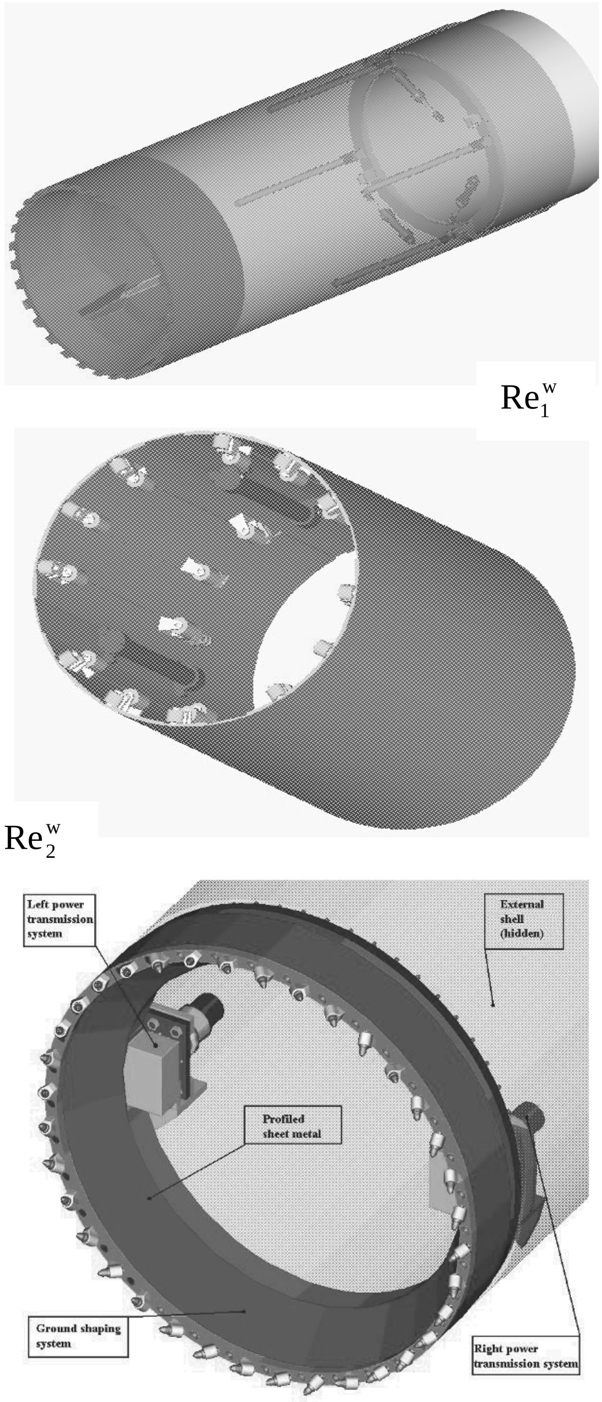


Fig. 10. Applied shaping ground opening ideas

Re_1^{w4} - internal body's rotational movement → 4 hydraulic bearings according to our own hydraulic bearings' modular system,

Re_1^{w5} - ground cutting → head's crown.

According to the other idea, relation Re_2^w Figure 10, shaping a ground opening is performed in three consecutive relations:

Re_2^{w1} - head's propelling → head's propelling systems include:

Re_2^{w11} - transformation of hydraulic energy into the mechanical one → Rexroth type A2FM hydraulic engines (Fig. 11),

Re_2^{w12} - mechanical energy transformation → Rexroth type GFBT2/T3 planetary gear,

Re_2^{w13} - head's toothed ring coupling relation → pinion.

Re_2^{w11}

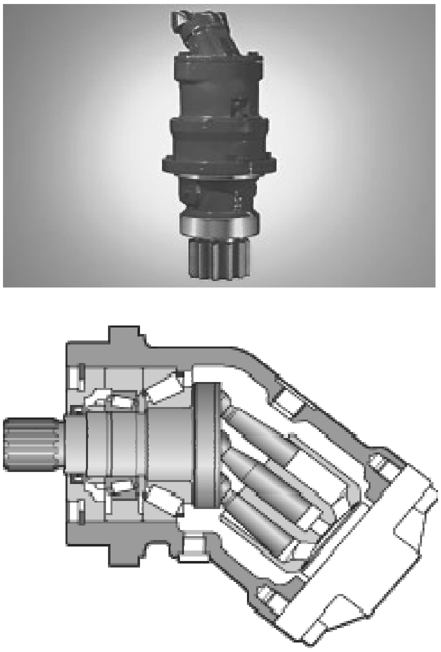
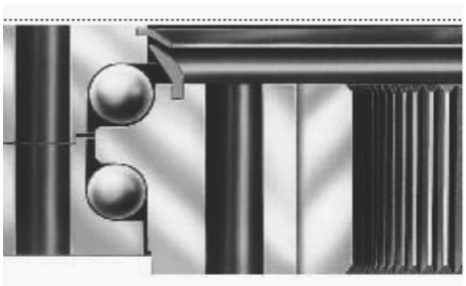


Fig. 11. Rexroth hydraulic engine



Re_2^{w2}

Fig. 12. Rother Erde large-size bearing

Re_2^{w2} - simultaneous rotational movement and mining-related loading transfer performance → head's bearing, Rother Erde double-row ball bearing with internal toothed ring (Fig. 12),

Re_2^{w3} - ground cutting → head's crown equipped in tapered knives like in the ripping head.

3.5. Transportation of the excavated material into the starting shaft

Excavated material's transportation into the starting shaft is performed by a basin-shaped belt conveyor, Figure 13.

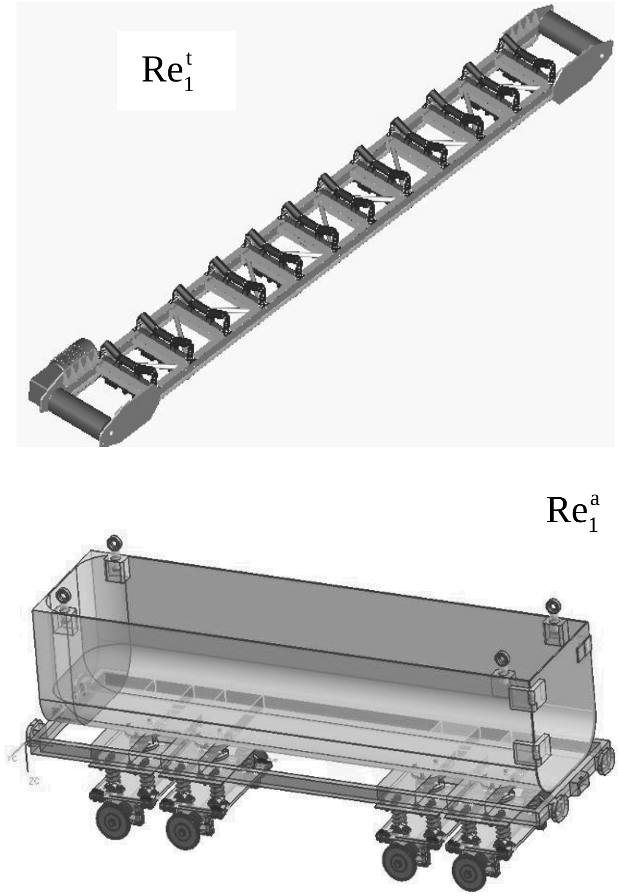


Fig. 13. Excavated material's transport

Belt conveyers were adjusted to the tunneling machine's constructional versions.

Transport from the conveyor to the starting shaft is performed periodically applying the use of a rail car, Re^a fig. 13. Both the conveyer and the car were designed according to our own ideas, basing on the catalogued sets and elements.

3.6. Tubes assembly and cars relocating

Tubes assembly is performed by a robot, see Fig. 14. This robot is equipped in an adequate gripper used when dealing with new tubes made of compound material.

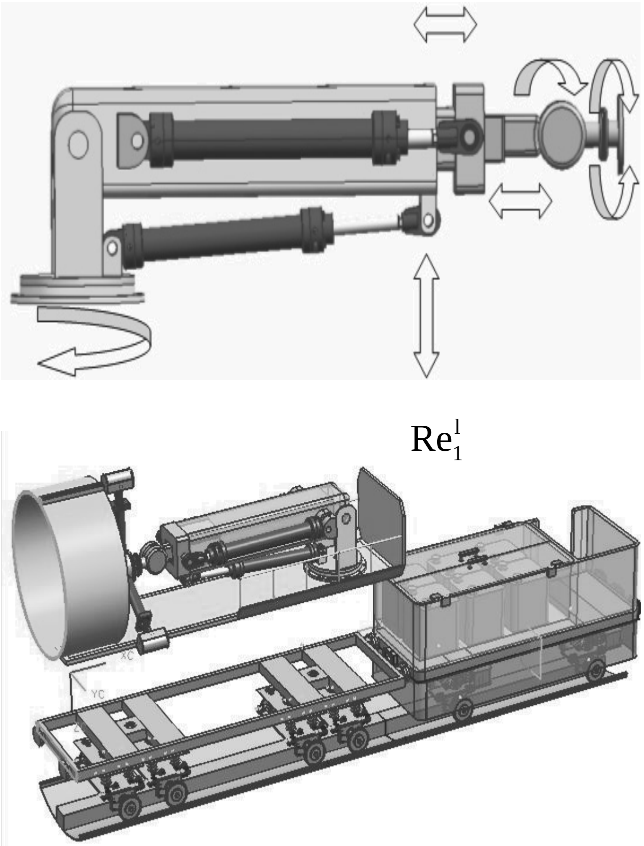
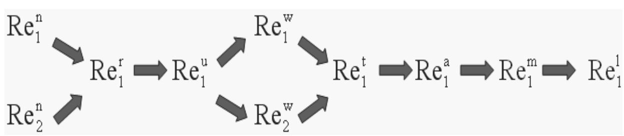


Fig. 14. Model of a tube assembly robot and a battery engine used to cars relocation

4. Project's results

The project resulted in exemplary constructional solutions for tunneling machines along with the use of robots characterized by two different system structures (principles of operation) described by the following relations, and constructional forms shown in Figure 15. For both sets and elements, parameter choice algorithms were elaborated, whereas for the constructing elements, constructional features choice algorithm was prepared.



FEM was used to verify the produced elements which were registered as 2D working drawings right after the verification. Series of types of tunneling machines will be created upon the basis of the elaborated quantitative constructional features selection algorithm.

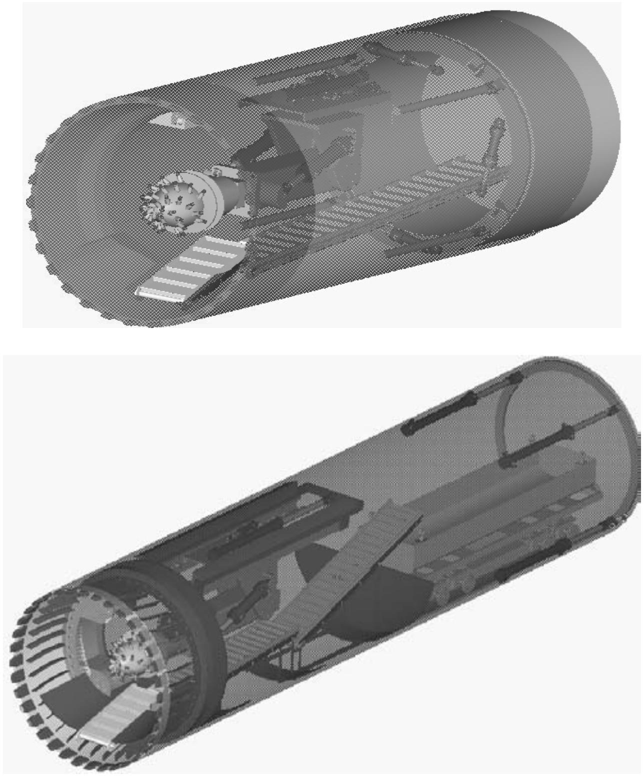


Fig. 15. Two constructional solutions for the trenchless tunneling machines

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