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DESIGNING UNIVERSAL DRIVES FOR TRENCHLESS REPAIR OF PIPELINES

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Abstract. The article presents the results of research on a new class of high carrying capacity drives distinguished by the simplicity of designing, universality and high carrying capacity at trenchless repair of pipelines. The paper also describes the dependences of the traction properties of these drives on the major factors of pipelines, technology and design.

Keywords: pipeline, trenchless repair, drive, torus technical means, carrying capacity.

1. Introduction

The urgency of a task for creating a family of effective trenchless drives is caused by the big extent of pipelines, their high deterioration and significant volumes of repair work. At present, in the majority of countries, except for developed ones, the trench ways of repairing pipelines are mainly applied which is connected to performing a great volume of excavations and blocking or braking transport streams causing destruction and subsequent restoration of road coverings, damaging and repeatedly planting green plantings. All mentioned above demands big expenses of work, time and money resources. The specified lacks can be eliminated by the perfection and introduction of trenchless ways for repairing pipelines instead of using trench ones.

For trenchless repair of pipelines, a way by means of composite coverings on their internal walls is widely applied. Thus, while employing trenchless drives, a vast variety of operations, such as broaching a cable, pipeline drainage, transportation of clearing tools (brushes, scrapers, pistons, etc.), covering internal walls of the pipeline, moving off video cameras, searching for defects etc. should be carried out. At the moment, to perform these operations, rather complex and highly specialized devices are applied. For example, they might include pumps for pipeline drainage, hoists for transporting clearing tools and caterpillar and wheel inside pipeline drives for moving off video cameras. Such drives are highly specialized, and therefore their number necessary for the maintenance of the full mechanization of works on the object is great enough and comes nearer to the number of operations conducted within this process. The design of the known drives is also complex and the number of details in each of them reaches some tens and even hundreds. All above mentioned results have a decrease in reliability, an increase in a complex of equipment and an increase in expenses at purchasing and applying them.

The above discussed lacks in part are eliminated in elastic torus mechanisms (Шихирин *и др.* 2006), and the standards of sleeve coverings (CIPP lining process) are defined in the USA standards – ASTM F1743–08 and ASTM F1216–09. However in both works, no comparison between these means is provided; the dependences of cinematic characteristics and traction properties on the major factors of influence are not revealed and design procedures of such devices for durability are not offered. Besides, in the previously specified works, the possibilities and features of applying torus mechanisms at trenchless repair of pipelines are not considered.

2. Stating Research Problems and a Technique for Making a Decision

Proceeding from the revealed lacks of the known technical means and the absence of the results of research on flexible mechanisms and coverings, the article puts forward and deals with the following problems:

- to develop and generalize technical decisions on inside tube drives with a high degree of universality passing the ability and simplicity of design;

– to establish the dependences of cinematic characteristics, traction and durability properties of the offered drives on the major factors influencing a pipeline, conditions for construction practice, technology and driving design.

The technique of making a decision on the first task is based on the theory about inventive problem solving tasks (Зуев 2006; Rodenacker 1970) and on the analysis of the revealed lacks of the known designs of inside tube drives. The criteria were chosen for the formalization of the task for universality as the maximization of a number of operations and a possibility of work using several standard sizes of diameters of the repaired pipelines. The minimum number of details in a created technical mean were chosen as a criterion for the simplicity of design, whereas for passability (pass through), the maximum of values overcoming the narrowing and corners of pipeline bends of a certain radius were accepted.

The technique of making a decision on the second task includes theoretical and experimental methods along with the use of system approach, mathematical modelling, mathematical statistics and planning an experiment. The technique, embracing mathematical models for the process of pipeline repair and research stands has been developed by the author and his students and is more carefully considered in the specified list of references (Емелин, Авдеев 2005a, 2005b) but not discussed in this article.

3. Results of Solving Tasks

The performance of a number of functions in pipelines depends on making an appropriate decision on the task, and therefore it is logical to search for such decision in the field of applying materials with high flexibility, thus following the author. As a result, (Емелин, Авдеев 2005a, 2005b), his creativity in collaboration with co-authors (Белобородов *и др.* 2003a, 2003b, 2005, 2008), the analysis of papers produced by colleagues (Храменков 1998; Белобородов *и др.* 1999) and the generalization of the received results, helped with making two decisions satisfying conditions for the task. One of those is based on the application of elastic toroidal devices filled with air (Fig. 1), whereas another is supported by the application of flexible sleeve-torus-shaped devices (Fig. 2).

Fig. 1 shows the drive that represents the so-called torus differing from a usual available device displayed in

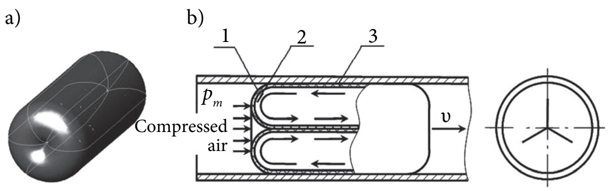

Fig. 1. Toroidal drive devices: a – general view; b – a scheme of movement in a pipeline; 1 – fabric sheathing; 2 – rubber chamber; 3 – nipple

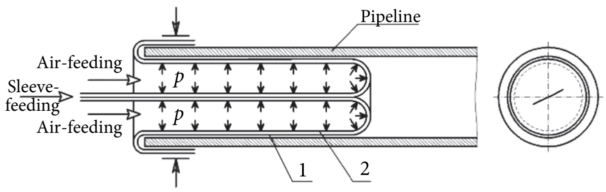

Fig. 2. Sleeve-torus-shaped drive: 1 – fabric sheathing; 2 – film sleeve

the form of a geometrical figure extended at length, executed as a hollow, filled with air and having an elastic chamber and a flexible fabric tire cover. Besides, its longitudinal aperture is closed (Fig. 1 a). The properties of such torus are based on its ability to nestle densely on an internal surface of the pipeline blocking a cross-section span of the pipeline and moving it by rolling caused by difference in air pressure at its ends P_m, Fig. 1 b.

One of the drives (Fig. 1) consists of 3 parts, the other (Fig. 2) – of 2 parts. The compressor or vacuum pump is used as an energy source in both decisions. In case of a vacuum pump, vacuum is produced in the space of the pipeline to the right from the torus (Fig. 1) or sleeve-torus-shaped devices (Fig. 2). In order to avoid leaking the compressed air submitted in the pipeline from its left end (Figs 1 and 2), introduction devices should be applied (Емелин, Авдеев 2005a, 2005b; Емелин 2006) which, along with the compressor and vacuum pump, are not displayed in these figures.

The possible schemes of applying the suggested torus devices for the mechanization of performing various works inside the pipe at lining, repair and pipeline operation are submitted (Fig. 3). As follows from the figure, torus-shaped means are characterized by high universality and can be used:

- for simultaneous and separate transportation on pipelines during their operation of several gaseous and liquid products;
- for repairing pipelines (by moving one or two similar devices of a polymeric composition or the rolled material moistened with glue along with simultaneous covering);
- for pipeline drainage;
- for providing definitions in the place of a leakage;
- muffling (blocking) a pipeline;
- rendering power or adjusting influence on other devices, playing a role of the pneumo-cylinder.

Thus, depending on the carried out functions, the considered device in each certain case can be related to the classes of drives, movers, mechanisms (transforming movement), industrial equipment or even machines (transportation of materials, transformation of energy, development of new production).

The possible schemes of sleeve-torus-shaped drive application are shown in Fig. 4. Thus, the specified technical means can be used for pipeline drainage and cleaning, performing transporting operations, broaching through the pipeline of a cable or halyard, fabric adhesive coverings.

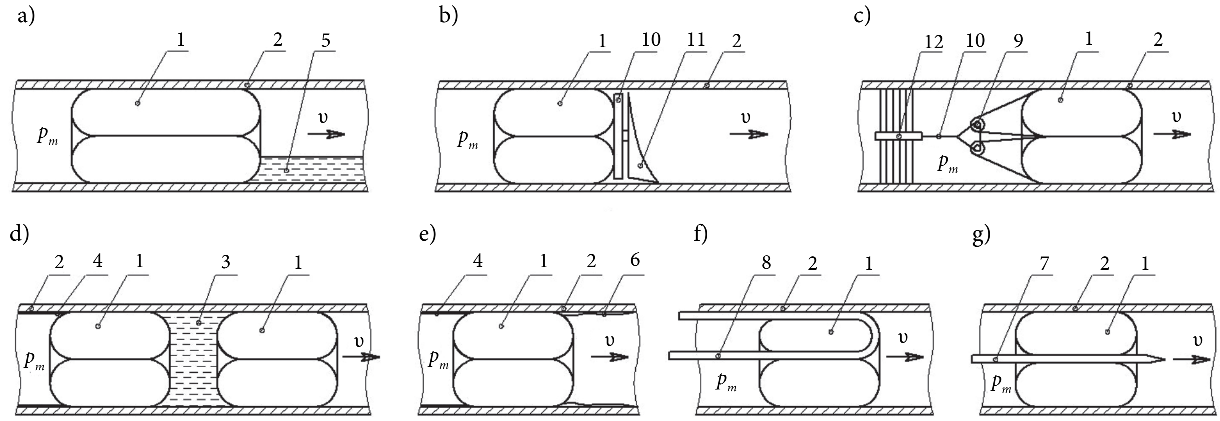

Fig. 3. The basic schemes of applying elastic torus shaped drives: a – removal of water or other liquid from the pipeline; b – clearing off the pipeline or the performance of transportation operations by a torus pusher; c – clearing off the pipeline or the performance of transportation operations by a torus puller; d – drawing a liquid kind covering material on an internal surface of the pipeline with the application of two toruses; e – smoothing, laying down and condensation of covering (covering formation); f – pulling a cable or halyard through the pipe; g – pulling through the pipe or rod, performing the function of the pneumo-cylinder; 1 – torus; 2 – pipeline; 3 – liquid covering; 4 – generated sheeting; 5 – moving off liquid from the pipeline; 6 – not generated covering; 7 – pipe, rod, etc.; 8 – cable, halyard, etc.; 9 – hook-on device; 10 – pushing device; 11 – scraper or other working actuator; 12 – brush or see item 11

As a result of analyzing the design and operating procedure of the suggested family of drives, it has been established that the latter have quite a few common features and differences.

The common features of these decisions are as follows: inside pipe applicability; high universality (performance of transportation functions, water removal from the pipeline, dragging a cable, restoration of the pipeline etc.); the identical mechanism of moving in pipelines (by means of inversion with simultaneous longitudinal rolling); covering application and design flexibility; the use of moving compressed air or vacuum; the application of not less than two casings the external one from which is air-penetrable and the internal one – air-tight; the absence of sliding friction between a pipe and the device; a possibility of moving inside the pipes of different cross-sections and longitudinal sections; a possibility of overcoming obstacles inside the pipe; an extremely small number of parts (in a torus – 3, in a sleeve – 2; to make shorter, further in the text, a toroidal shaped drive is called *torus* and sleeve-torus-shaped drive – *sleeve*); specificity and a small level of scrutiny – in more advanced works by academician I. I. Artobolevsky, the founder of this school (Артоболевский 1981) and other researchers, similar devices are missing.

Differences in these two designs of the inside pipe drives include: a torus has closed cavity, while a sleeve has an open one; in the torus, three different modes of air pressure are used (before, inside and behind it) while in the sleeve, two modes of pressure are applied (inside and behind it); the torus operates due to difference in air pressure before and behind it, while the sleeve operates due to difference in pressure inside and behind it and can serve both as a device and as a technological material for the restoration of the pipeline while the torus can serve only as a device as it has rather small dimensions (usually not more than 3 diameters of a pipe) and all of them are alike. Sleeve dimensions of length are usually two times bigger than its diameter. The torus stops at the presence of through apertures in a pipeline while the sleeve – does not; the torus can be used as a choke and for dividing several products at their simultaneous transportation, whereas the sleeve cannot.

The character of point movement for torus-like and sleeve-torus-like drives is identical in many respects. Especially it concerns the points of an inversion zone and the points located on the axial-longitudinal part of these devices. As a result of researches (Емелин, Авдеев 2005a; Емелин 2006) on the kinematics of the elastic torus-like drive carried out by the author, it was established that:

- considered drives move inside the pipeline rolling with no slipping mode; consequently, the wear processes of its elements take place; in case of torus movement with a constant linear speed, separate points of its surface during different moments of time are under conditions of rest and a uniform, accelerated or slowed down movement takes place;
- with an increase in drive length, the speed and acceleration of its points on a span of a uniform movement (on the axis of the mechanism) do not depend on their diameter and length; moreover, on a span of a variable movement, they do not depend on length and are proportional to diameter; the speed of the points on a span of a uniform movement is 2 times greater than that of the movement of the weight centre;

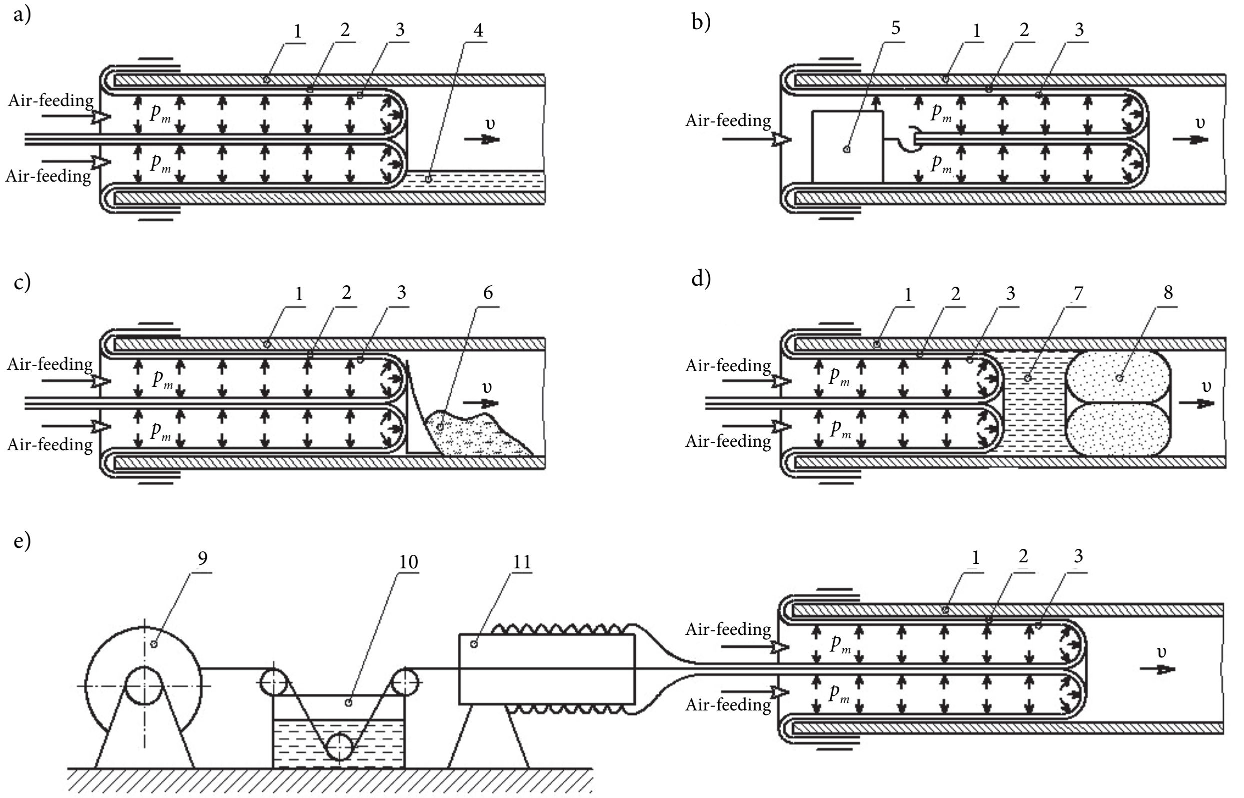

Fig. 4. The basic schemes of applying sleeve-torus-shaped drives: a – pipeline drainage; b, c – firm transportation and loose bodies; d, e – drawing on the internal walls of pipeline polymeric and fabric adhesive coverings by means of (d) colouring and (e) pasting: 1 – pipeline; 2 – fabric sheathing; 3 – film sleeve; 4 – water; 5 – firm body; 6 – loose body; 7 – liquid polymeric structure; 8 – torus- shaped mechanism; 9 – drum with fabric sheathing; 10 – bath with glue; 11 – branch pipe and film sleeve (a device for a tight input of the sleeve-torus-shaped mechanism in the pipeline is not shown in the figure)

- at a rational for practice linear speed of a drive and the nomenclature of used pipes, the acceleration of the points of its surface do not exceed 10% from the acceleration of free falling bodies and will not lead to its overloading by inertial forces;
- at the expected modes of drive operation, the risk of their part destruction, owing to wear, is insignificant because elasto-plastic materials, fabric and film parts possess increased flexibility and the number of bending – unbending cycles for 10 years rated service life will not exceed 500 thousand.

Theoretically, conditions for the movement of such drives are also experimentally determined. Thus, for maintaining the reliability and steady moving of a torus as a drive, it is necessary to appoint air pressure in the chamber of the torus about 30÷90 kPa at a minimum of 10 kPa; driving torus air pressure is about 10÷50 kPa; torus length is within the limits of its 3 diameters; chamber thickness is about 0.7÷2.0 mm; the diameter of the measured torus under the pumped up condition outside the pipeline is 2÷4% larger than that of the last mentioned one.

The results of experimental research on the traction properties of the torus at the stand (Емелин, Авдеев 2002) were obtained by the author (Емелин, Авдеев 2005a; Емелин 2006) (Fig. 5) and are as follows:

- the character and presence of extreme values considering the dependence of torus traction efficiency on traction loading and air pressure inside it (Fig. 5) are shown with reference to the example of applying it in the pipelines of small diameters (internal diameter makes 68 mm);
- along with an increase in internal air pressure in the torus from 50 to 90 kPa, its greatest possi-

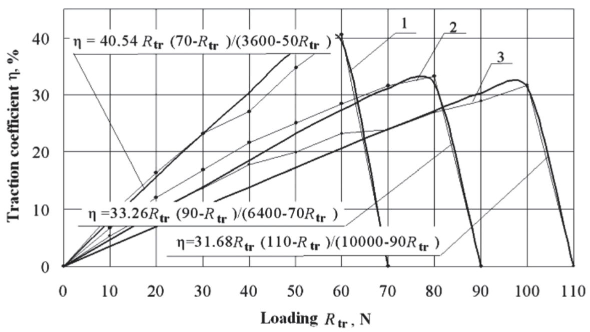

Fig. 5. The dependence of torus traction efficiency (drive) on traction loading at different values of air pressure inside the torus: 1 – P_{ins} = 50 kPa; 2 – P_{ins} = 70 kPa; 3 – P_{ins} = 90 kPa

ble traction effort grows and the highest traction efficiency is reduced from 42% to 32% (for the pipeline with an internal diameter of approximately 68 mm); at an increase in the diameter of the pipeline and moving air pressure, a tendency to an increase in the values of efficiency and traction efforts is observed;
- optimum air pressure in the torus is in the range of 50÷90 kPa; under lower pressure, the greatest traction effort is reduced and broken steady torus rolling takes place; under higher pressure, the losses of capacity on its movement lowering traction efficiency grow.

As a result of research (Емелин, Авдеев 2005a, 2005b), the passability (passing through) of torus - like and sleeve torus shaped devices as vehicles depending on the parameters of their design, the pipeline and technology of application are established by the author:
- devices can overcome narrowing pipelines up to 25% from their nominal diameter. However, in case of torus - like drive, necessary driving torus air pressure grows 1.5÷2.0 times and useful maximum traction loading decreases in 20% taking into account all modes of air pressure inside the torus;
- mechanisms are capable to overcome local narrowing (diaphragms, welded seams etc.), thus reducing the diameter of the pipeline up to 1.4 times; however, for this purpose, it is necessary to increase moving air pressure up to 1.5÷1.6 times; traction effort of such devices at the moment of transition through a diaphragm decreases less than at the entrance of the pipeline of a smaller diameter and is equal to the diameter of an aperture in the diaphragm;
- devices are capable of passing the bends of the pipeline with a corner from 120° to 180° at the heaviest radius of a bend for zero movement; when passing a bend of the pipeline of about 160°, a necessary increase in moving air pressure makes 1.25 times, with a bend of 140° – 1.7 times, and with a bend of 120° – 4.0 times; minimum necessary air pressure in the torus for a steady passage of a bend of the pipeline at a corner of 160° should make 30 kPa, at a corner of 1400 – 40 kPa and at a corner of 1200 – 50 kPa;
- the lowest air pressure in the torus for its steady movement in pipelines without bends and narrowing should be not less than 10 kPa.

The paper proposes the features of calculating the strength of the parts of a torus-like drive suggested by the author (Емелин, Авдеев 2005a; Емелин 2006). Calculating the strength of a sleeve torus drive can be executed by analogy to this work. The calculations and obtained results of the experiments conducted by the author (Емелин, Авдеев 2005a; Емелин 2006) show that the application of the suggested means in the process of repairing trenchless drives of pipelines will allow to lower expenses, in comparison with trench technology, 1.5÷2 times and more.

4. Conclusions

1. The family of new inside tube drives, including elastic torus-shaped as hollow lengthened torus and sleeve-torus-shaped as half hollow lengthened torus is acknowledged.
2. The paper has examined the design of these two kinds of drives possessing a high degree of universality (a possibility of performing 7 and 5 operations accordingly) simplicity (each of the drives consists either of 3 or 2 parts) and passing ability (a possibility of overcoming narrowing up to 25% from the initial diameter of the pipeline and bends with the corners of 120÷180° at zero radius).
3. 11 common features and 7 differences of the offered drives are revealed.
4. The dependences of the traction properties of the considered drives (traction effort and efficiency) on the characteristics of the pipeline (diameter, narrowing size and band corner), a drive (diameter, length, internal air pressure and chamber thickness) and technologies (driving air pressure, bay length) are determined.

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