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Development trends in belt transmissions with V-belt

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Abstract. The continuous increase in the use of the transmissions with V-belt, the introduction of new materials for the production of belts and the development of new manufacturing techniques have become the reason for undertaking research works on the possibilities of increasing the load capacity and durability of belts as well as reducing their influence on the environment. It is important to know the latest mechanical and rheological characteristics of the belts in terms of their strength characteristics and fulfilment of the conditions for the correct operation of the transmission. The results of these works will make it possible to determine the scope of applicability of these belts in propulsion and transport technology as well as to develop new geometrical forms of pulleys and V-belts.

1 Introduction

The use of V-belts in belt transmissions dates back to the beginning of the 20th century, however, in the last dozen or so years, thanks to intensive development of the chemical industry, many new materials used in the production of drive and transport belts have been developed [1-3]. The development of belt transmissions concerns new materials [4-7], geometric forms of belts [8-9], pulleys and intermediary drive transmission elements [10-15]. The source of incorrect operation of belt transmissions can be inaccuracies in the assembly of machines and devices [16,17], unbalance and shape of elements in rotary motion [18-21], wear and tear of elements, change of belt transmission temperature [22, 23].

It is assumed that the use of V-belts was initiated in 1917, when John Gates first used this solution in a car drive. The functional features of belt transmissions also contributed to the research and development works of the scientific centres and belt manufacturers on their geometric, material, strength and dynamic features [24-30]. Thanks to their advantages and relatively low production costs, V-belts and multi-ribbed beltshave found very wide application in many branches of industry [31-35].

2 Development trends in the construction of drive and transport belts

According to the paper [36, 37] three main trendsof belt construction development can be distinguished: structural, material and manufacturing techniques concerning ones.
The first of these trends comes down to the development of new geometrical features of belts and pulleys or to modifications of the existing ones [38-43]. This results in changing the cross-sectional area of the belt and limiting the part of the cross-section below the so-called neutral axis to the necessary minimum [44]. An example of such an approach can be the modification of the classical belt, which resulted in the formation of a narrow-profile belt. Its cross-section has the shape of an isosceles trapezoid, and in its construction a load-bearing layer (made of cords), a flexible layer (made of rubber or caoutchouc) and a fabric-rubber layer can be distinguished. The narrow-profile belt is entirely wrapped with a vulcanized tape (the so-called wrapper). Thanks to such a structure, it is characterized by increased adhesion, strength, elasticity and low stretchability [45-50].
A different trend of belt construction development was applied in case of composite belts of Poly-V type. In order to combine the advantages of V-belts and flat belts, the shape of cross-section in the form of multiple triangular or trapezoidal projections was developed. This made it possible to use one type of belt interchangeably in those drives where flat or V-belts were previously used. Several layers can be distinguished in the cross-section of these belts:

- a dorsal one, reinforced with fibre to ensure lateral stiffness of the belt,
- a carrier one, made of polyester, aramid or polyamide fibres, providing increased power transmission,
- filling one, made of a mixture of materials with high abrasion, high temperature and hydrocarbon influence resistance,
- protective one, with an elastomeric structure, thanks to which the belt adheres better.

Thanks to its structure, the composite belt is very bendable, which makes it possible to use it in belt transmissions with small diameter pulleys. It can be used for high rotational speed operation as well as for power transmission up to 600 kW. Another advantage of this solution is the possibility of obtaining a 1:60 ratio (when using V-belts, this value is 1:20). In addition, the design of these belts makes it possible to eliminate the undesirable phenomenon of so-called circulating power, resulting from the parallel use of single belts of different lengths.
The material trend of the belt development is based on the modification of mechanical and rheological characteristics of the materials used in production in order to extend the scope of their application. The materials used in the production of belts must meet different, sometimes opposing requirements, which results from the variety of belt applications and their function in the belt transmission. The main characteristics of these materials are those that ensure that the coupling of the belt to the pulley is strengthened and thus that high torques and speeds are transmitted with the required durability. The primary factor affecting belt life is the fatigue resistance of the material to bending and energy dissipation due to internal friction. In addition, belt life depends on the resistance of the material to permanent deformation during the operation of the belt transmission.
Increased belt life can be achieved by not closing the side surface of the belt with a wrapper and by inserting filler into the part of the belt that is below the neutral axis, the fibres of which are oriented laterally to the direction of the belt movement. This filler may be rubber with a suitable admixture of synthetic fibres. This gives rise to several advantages, which may include: high elasticity of the belt in the direction of its movement, considerable stiffness in the transverse direction, greater resistance to abrasion and reduction of

permanent deformations. The paper [44] presents non-classical models of materials used in machine design, formulates constitutive compounds for rubber-like and porous materials and gives examples of design of structural elements used in complex load condition.
The third trend of belt development is related to the techniques of their manufacturing. The development of belt manufacturing methods was initially related to the availability of natural materials - the first belts were made of leather, and then mixtures based on natural caoutchouc were used to manufacture them. At present, composite materials are used for this purpose, and the manufacturing methods are selected according to the type of belt.
In order to manufacture single V-belts, three methods can be used, depending on their structure and materials used. Rubber compound belts are made using the first of these methods. Their performance characteristics are obtained after applying pressure forming at elevated temperatures (vulcanisation in an autoclave). The material used for such belts is coated with additional compounds. The prepared rubber mixture contains, apart from elastomer and chemicals needed for vulcanization, also sulphur and so called accelerators, as well as zinc oxides, wax and up to 30% of other fillers. The second method of manufacturing classic V-belts consists in using the influence of temperature to give shape and then cooling to obtain the final shape. Belts manufactured from thermoplastic materials can be formed using this method [Fig. 1]. Its advantage is that the belts can be recycled. The third method consists in making the same or similar elements which are then joined into segmented belts of the desired length.

Fig. 1. Production of thermoweldable circular profile belts.

Segmented belts are manufactured from segments punched from two- and three-layer conveyor belts and riveted together or connected by means of an appropriately shaped tip. The segments are punched at stamping plants using a suitably shaped punch and counter punch.
Depending on the properties of the belt material from which the segments are punched out, the belts are obtained that are approved for contact with food, oil and grease resistant, with a specific electrical conductivity, etc.

Figure 2. Example of belt segments to be joined without rivets.

Segmented belts with riveted connections are used when other ways of connecting their ends are difficult. Belts without rivets (Fig. 2) are used when their operation with higher speeds and in more difficult conditions is required.

3 Classification, characteristics and use of V-belts

According to the general classificationshown in Fig. 3, the V-belts are divided into single and composite ones. Single V-belts are divided into: narrow-profile, narrow-profile toothed, standard, wide-profile and special ones. Among the composite belts, the following ones are distinguished: narrow-profile, standard, multi-spline Poly-V, double-sided belts. In the further part of this paper, selected types of belts will be briefly characterized, taking into account their functional and geometric features and applications. Their detailed characteristics are included in catalogues of such companies as ContiTech, Sanok Rubber Company, BEHAbelt and Fenner Drives.

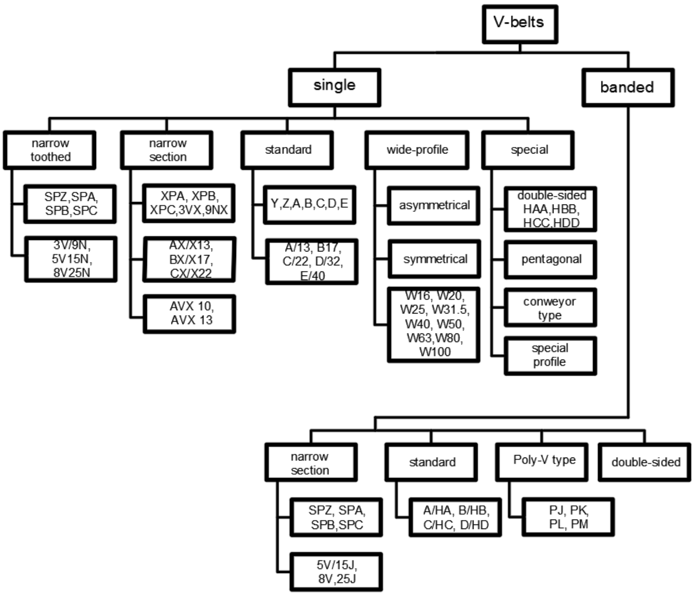

Fig. 3. Classification of V-belts.

3.1 Single V-belts

Among the single narrow-profile belts, three groups can be divided. The first one is made up of reinforced belts, designated with SPZ, SPA, SPB and SPC, the second one is made up of belts designated with 3V/9N, 5V/15N and 8V/25N, and the third one is made up of special material belts without textile wrapper, designed for the heaviest loads, also designated with SPB and SPC (the manufacturers designate the belts in this group by their own names, sometimes with an indication of the material hardness; this method of designation may cause confusion in the belt systematics, but due to its characteristic features, this group of belts clearly differs from the other ones).
Single narrow-profile reinforced belts (SPZ, SPA, SPB and SPC) are made up of a rubber core, a tension member consisting of several cords and a rubber cap (in the upper part of the belt). The whole is surrounded by a wrap of rubber impregnated fabric. The single narrow-profile reinforced belts have the following characteristics:

- width to height ratio: approx. 1 to 1.2,
- antistatic properties,
- possibility to be used in tropical climates,
- resistance to hydrolysis,
- increased power due to low stretchy cord,
- moderate resistance to oil,
- resistance to dust and dirt influence,
- recommended operating temperature range from -30 °C up to +80 °C,
- electrical conductivity according to ISO 1813.

SPA, SPB, SPC and SPZ belts are designed for high performance drives used in general engineering. Typical areas of application are compressors, fans, construction machinery and various gardening machines.
Single narrow-profile belts designated in the catalogues with 3V/9N, 5V/15N and 8V/25N, are designed for many applications in the mechanical industry, e.g. in air extraction systems, mills, mixers and pumps, as well as in sawmills, truck shafts or conveyors. In most cases a single narrow-profile belt can replace a standard belt. The advantage of this solution is the ability to transmit more torque and achieve a speed up to 33% higher in comparison with standard belts.
The heavy-dutySPB, SPC type single narrow-profile belts without fabric wrapper, are an ideal solution for drives requiring increased strength. They use a low stretch aramid fibre reinforcement element. They are most commonly used in agricultural machines, stone crushers, mixers and other special machines. Thanks to their properties, they provide the possibility to transmit up to 70% higher power in comparison with standard V-belts. In addition, the surface of the narrow-profile belt not covered with fabric ensures better heat dissipation.

3.2 Single narrow-profile toothed belts

Single narrow-profile toothed belts can be used in drives characterized by:

- very small pulley diameters,
- high engine rotational speed,
- high torque values,
- high linear velocity,
- possibility to work in high ambient temperature.

They make it possible to replace classic multi-stage drives with single-stage transmissions. As they can transmit high loads and are highly flexible, they can be used in compact drive systems. This makes it possible to reduce the number of V-belts in one set or to reduce both the pulley number and diameter sizes.Thanks to the development of new design solutions and new materials, these belts also have a high degree of flexibility in the longitudinal direction and a good lateral rigidity. This ensures that the high requirements related to the implementation of modern drive systems are met and enables their new applications in many areas of mechanical engineering.

3.3 Standard single belts

Single belts with a standard cross-section, due to their width to height ratio of 1.6, are the best solution in difficult working conditions and with not very good quality of transmission elements and their assembly. The areas of application of this group of belts are mostly gardening and agricultural machines. They can also be used in transmissions with flat pulleys or in cases where one of the wheels is flat.

3.4 Single wide-profile belts

Single wide-profile belts are manufactured exclusively as toothed belts and are designed for torque transmission in infinitely variable transmissions. The essence of such drives is that one or two wheels are made of sliding discs, whose current position determines the diameter on which the belt operates. Shifting the discs causes a change in the transmission ratio. Belts of this kind have been standardized according to European and American standards. Therefore, belts of similar length but with different cross sections are available. These belts have additional names (e.g. Wariflex, Waridur), indicating their hardness. Wide-profile belts with asymmetrical cross-sections and various teeth are also produced, used for properly prepared pulleys. The teeth ensure improved bending of the belt on the pulley. To prevent belt vibrations, some manufacturers use teeth unevenly spaced around the circumference. Single wide-profile belts are used in both the automotive industry and agricultural machinery.

3.5 Special single belts

Double-sided, thermoweldable and segmented belts will be presented as examples of special single belts.
Double-sided (double-acting) belts are designed for drives used in all sectors of machine construction and operation as well as in agricultural machinery. They are distinguished by the fact that they can be used in drives that are constructed of several pulleys in one plane and in which there are changes of direction of rotation.
The second group of special single belts is made up of thermoweldable belts. They are manufactured of high-quality thermoplastics made of polyurethane and polyester. They are used both in classical drive technology and in conveyors. The thermoweldable belts are mostly manufactured in six variants of different hardness. In order to identify them unequivocally and correctly, the colour of the belt is used as an indicator of their hardness. The precursor in the production of this type of belts was Beha Company, which also proposed their systematics in relation to colours.
Six types of thermoweldablebelts, made of materials of different hardness, marked according to Shore scale, will be discussed here. Belts made of PU 75 A type polyurethane (80 Shore A, red) are characterized by high quality and considerable flexibility and are particularly useful in conveyors and in transmissions with small pulleys. They are used to transport frozen goods. Their main advantage is that they can be used as both drive and transport belts. Belts made of PU 80 A type polyurethane (84 Shore A, transparent) are used mainly in food industry, in processes where their direct contact with meat, fish, fruit,

vegetables, bread etc. is necessary. Belts made of PU 85 A type polyurethane (88 Shore A, green/yellow), which is a medium-hard material, are an ideal solution for power transmission in machines and equipment, including various types of conveyors.
Belts made of PU 90 A type polyurethane (92 Shore A, white) are designed for heavy duty applications due to their excellent flexibility and damping properties. They often replace conventional V-belts in conveyor equipment. On the other hand, belts made of 40 D type polyester (92 Shore A, beige) and 55 D type polyester (98 Shore A, blue / beige), i.e. of materials characterized by considerable hardness, are designed for heavy duty applications and temperatures from -28°C up to +100°C. They are used in roller conveyors in glass and tile manufacturing plants as well as in shredders and crushers.
The third group of special single belts presented here are segmented belts, manufactured with fasteners in form of rivets or without rivets. The use of rivets facilitates the assembly of the belt from the elements, but has a negative impact on its durability. The segmented belts have a unique design and are made of high-grade composite materials, which provide many benefits such as time savings and reduction of production costs.
Among the main advantages of belt transmissions with segmented belts,the following ones are to be mentioned:

- possibility of easy and quick installation,
- extended service life compared to that of standard drives,
- reduced stockpiles,
- possibility to shorten the time of repairs and periodic reviews,
- compact drive design,
- a little antistatic resistance,
- reduced vibrations and noise,
- ability to withstand significant loads,
- easy identification of characteristics and intended use based on the colour of the belt.

The segmented belts are made of polyurethane elastomer reinforced with polyester fibres, which ensures high strength even in the most demanding working environment. The HPC belt series consists of Z/10, 3L, A/13, B/17 and C/22 belts, designed for medium duty industrial drives, and of D/32 size belt, used in equipment exposed to periodic shock load changes. The HPC belts are far superior to standard rubber belts in their resistance to water, oils, greases or other industrial chemicals. They are also much more resistant to abrasion and extreme temperatures (from -40°C up to +120°C).
Applications for segmented belts are becoming more and more numerous, from setting skittles,through drives for baggage conveyors at airports, drives for carpentry equipment or light bulb transporting on the production line, to drives for crushers, equipment for transporting blocks in brickyards and saws for cutting stones.

3.6 Composite V-belts

Narrow-profile composite belts are designed to work in transmissions with pulleys spacedat a considerable distance, used in very difficult conditions, especially when there is a very high level of dust during operation (as in the case of crushers and stone planers as well as of agricultural machinery). Thanks to the use of lateral rigid reinforcement, the composite unit is resistant to torsion and excessive vibrations of individual belts.

3.7 Standard composite belts

Standard composite belts are designed for use in transmissions subject to high dynamic alternating loads. They use an additional (connecting) layer of material in order to ensure equal length of individual belts working parallel on pulleys with several grooves.
However, in case of manufacturing errors, e.g. misalignment or lack of shaft parallelism, the connecting layer of the belts was destroyed in a short time. Therefore, belts of this type are no longer used in newly designed drive systems. Their area of operation is limited to agricultural machines, woodworking machines and ventilation systems.

3.8 Poly-V-type composite belts

Poly-V belts are the oldest group of composite belts. They are made up of three main layers: the base layer, the supporting layer and the wrapper. The base layer, made of highly abrasion-resistant polychloroprene, consists of parallel V-shaped wedges arranged along the section of the belt. This wedge shape ensures good frictional adhesion and uniform load distribution across the entire width of the belt. The supporting layer consists of polyester cord, which is continuously wound across the entire width of the belt. The third layer, the so-called wrapper, is very flexible and provides long-term protection of the supporting layer. The running side of some belts of this type is covered with fabric.
Poly-V type belts can operate with significant transmission ratios (up to 1:40), and their structure ensures extremely high flexibility, which allows for proper functioning of belt transmissions with relatively small diameter pulleys. The advantage of belt transmissions with such belts is the possibility of obtaining high linear velocity of the belt (up to approx. 60 m/s) thanks to appropriate structure and materials used. Due to the exceptional flexibility, Poly-V belts can be bent up to 120 times per second. Excellent frictional coupling and load distribution across the entire belt width ensure 98 percent efficiency. To reduce noise emissions, the belt wedges are covered with an additional layer of fabric or irregular transverse cuts are made on them. The belt transmissions using this type of belt produce the slightest vibrations, run quietly and transmit the highest torque. Poly-V type belts are used in many areas of drive technology, and the PK series is very often used in car drives.
Poly-V type belt distributors also offer belts with teeth on the dorsal surface, as well as with additional material layers to facilitate their adhesion.

3.9 Double-sided composite belts

Double-sided composite belts provide the possibility to achieve high gear ratiovalues and belt speeds with small diameter pulleys and two-way operation. Double-sided composite belts can be used when a change in the direction of rotation of the pulleys is required, e.g. in drives of shredders used in the milling industry, transport lines in bakeries, agricultural machinery (cultivators), textile machinery (carding machines) or gardening equipment (garden tractors).

4 Summary

The V-belts used in belt transmissions are most often made of composite materials with a composition based on plastics. So far, traditionally, steel or polyamide cords have been used in the production of transmission belts forthe carrier layer, a rubber or caoutchouc for the flexible layer, and a fabric-rubber composite (vulcanized cloth or cord tape) for the protective layer. Nowadays, composites and materials of various structuresare used in the production of transmission belts. Detailed information about the applied solutions is usually protected and manufacturers do not publish them. The commonly available data concern mechanical properties of the belts in question and their resistance to the operating environment.

The knowledge of the components of which particular types of belts are made is necessary for their proper recycling [51-57]. Two methods can be used for this purpose. The first one is to crush and grind them, and then granulate the resulting material and reuse it. The second one is to incinerate them, but in this case special attention must be paid to the safety of this process so that toxic chemicals do not get into the atmosphere. The data published in catalogues by belt manufacturers are to be the basis for the selection of belts by designers. However, it is also necessary to take into account various operating conditions, structural defects that appear during use, as well as contamination and malfunctions.

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