V-BELTS IN ELEVATOR AND ESCALATOR DESIGN

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Summary

V-belts are used throughout the design of elevators. However, this fact is rarely acknowledged in the specialist literature despite the low noise levels and reliability that make the V-belt drive one of the most widely used mechanisms for door operators.

As an introduction, therefore, various designs of door operators will be presented which use the V-belt drive. These systems alone provide a clear illustration not only of the particular advantages of the V-belt drive, but also of its limitations as a machine element.

Following this is a demonstration of how these advantages make the V-belt suitable as the main drive system. Various examples of elevator and escalator design will be used to show the development of the V-belt drive up to its most modern and up-to-date form.

1. Elevator Door Operators with V-Belts

The main purpose of the door operating mechanism is to convert the rotational movement of an electric motor into the linear horizontal motion of the door panels. One of the most beneficial solutions for this is the crank drive: the uniform rotation of a crank about 180° produces a horizontal motion which starts gently and, after reaching a maximum velocity then ends smoothly (see Figure 1).

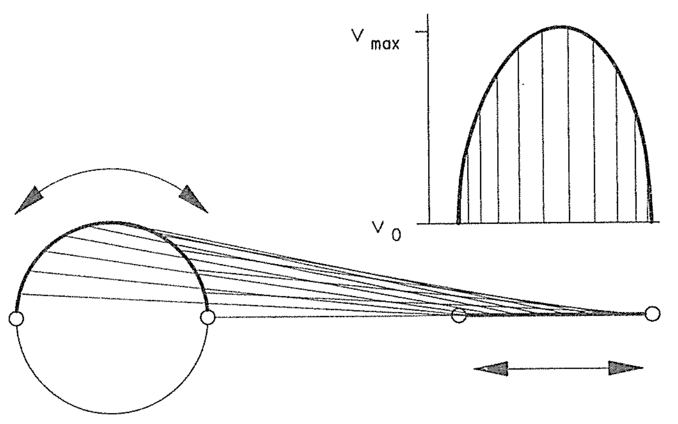


Figure 1

The crank must rotate relatively slowly to meet the speed desired for the door panels. This then calls for a reduction in gearing between the motor shaft and the centre of the crank. A wide range of gears are used to achieve this effect. For reasons of economy, low noise, reliability and low maintenance requirement a V-belt drive is often employed. However, this means that the desired reduction cannot be achieved in a single step but that two are needed. The required power has to be transmitted consecutively by the two stages. In the second stage, however, the rotational speed is lower and consequently a higher torque has to be transferred. Designers have tackled this problem in a number of different ways.

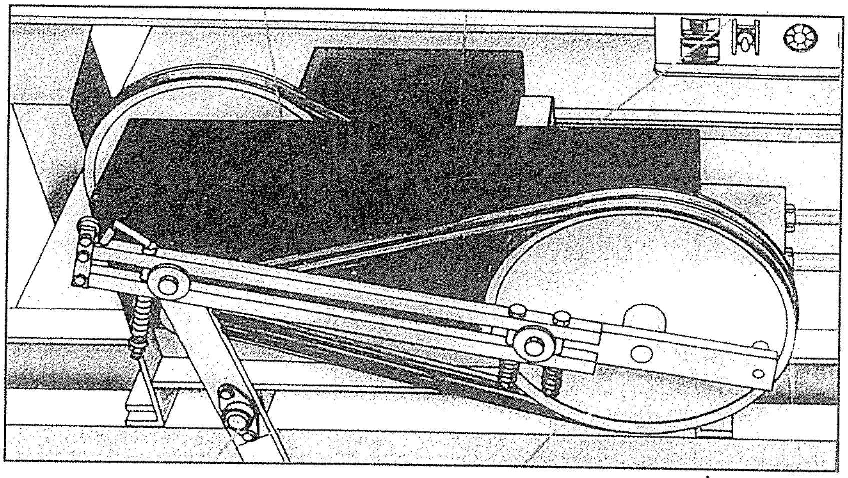


Figure 2

Figure 2 shows how the advantages of the V-belt drive can be used systematically for both stages. A single V-belt is used for the first stage, in the second stage two or more belts are employed to transmit the higher torque.

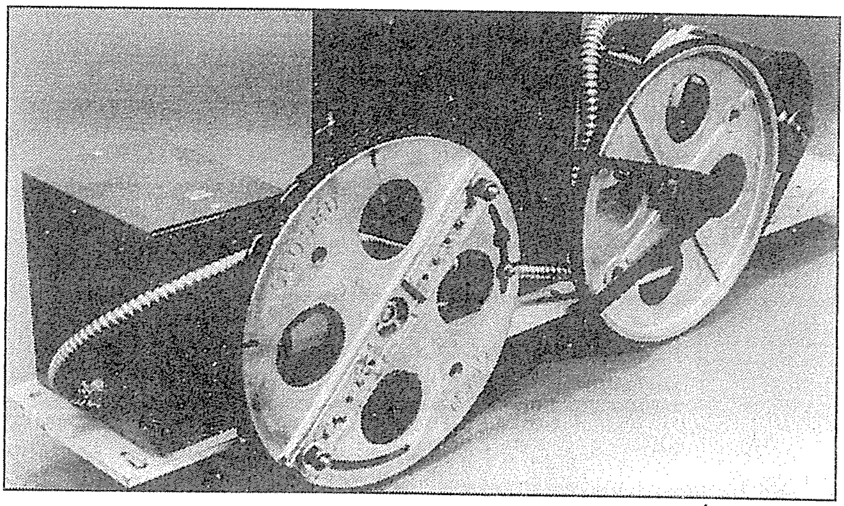


Figure 3

For the second stage in Figure 3 the designer has used a robust chain drive, which enables significantly higher torques to be transmitted. Since the speed has already been reduced for the second stage, the noise of the chain is less critical, the only remaining disadvantage is that the chain has to be lubricated.

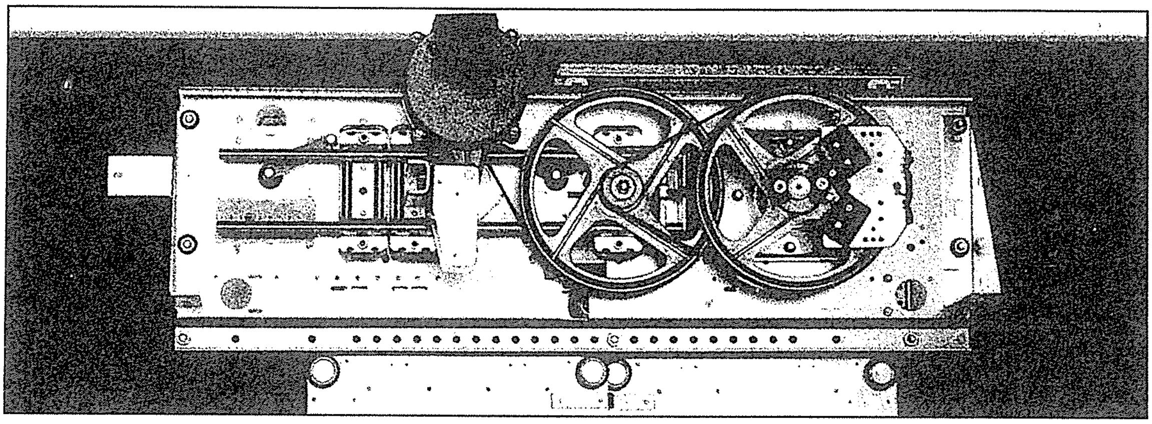


Figure 4

Smaller doors are able to use the mechanism shown in Figure 4, where a ribbed V-belt is employed for the first stage, thus enabling the diameter of the driving sprocket to be greatly reduced. A minimum diameter of 20 mm is sufficient for the profile, PJ, of this so-called poly-V-belt, whereas a minimum of 50 mm is required for the V-belt profile, 3V, of the second stage. The advantage of this solution is that the total transmission ratio is achieved with small diameters and the drive is very compact.

In order to move large doors with their correspondingly greater masses, this solution can be augmented by a third stage with a chain, giving the mechanism shown in Figure 5.

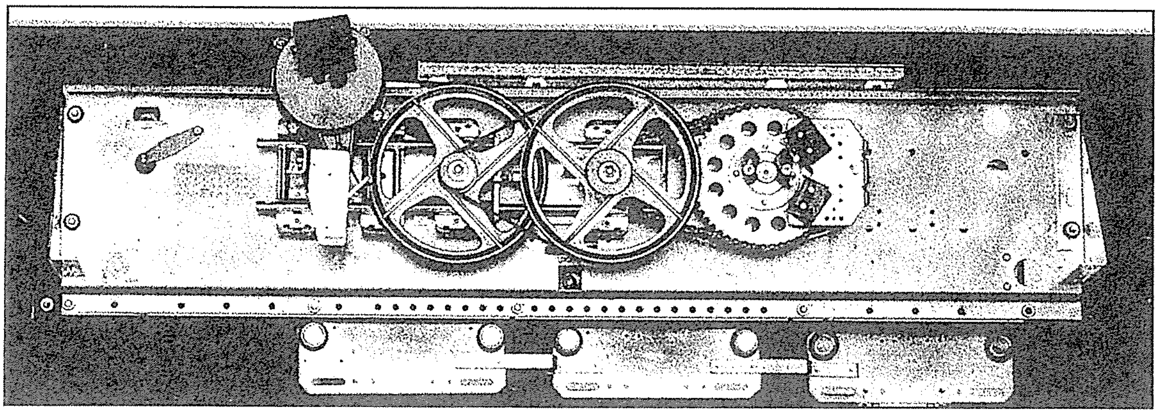


Figure 5

The door operators described above are mass-produced and have been operating reliably for decades. Every elevator engineer is familiar with these types of mechanism involving V-belts and does not regard them as anything out of the ordinary.

2. Main drive systems for elevators and escalators incorporating V-belts

The situation is different when V-belts are used for the main drive. Many elevator engineers are not at all familiar with such designs although thousands of drives incorporating V-belts have been built for elevators and escalators. Most attempts at incorporating V-belts into such drives in western Europe date from 1950 and subsequent years, when narrow V-belts (wedge belts), a new improved design, came onto the market. In the following I will describe some of the most important of these designs.

2.1 V-belts as a clutch between motor and worm gears

The most common design using V-belts involved linking the motor and worm gears by a one-stage V-belt drive with a speed-changing ratio. This made it possible to position the motor either above or to the side of the worm gears. The motor-gear unit thus became considerably shorter - a particular advantage for small contract loads and cramped machine rooms. As an example I include Figure 6 of an elevator drive mechanism produced by Stahl. However, similar systems have been built by many other elevator companies.

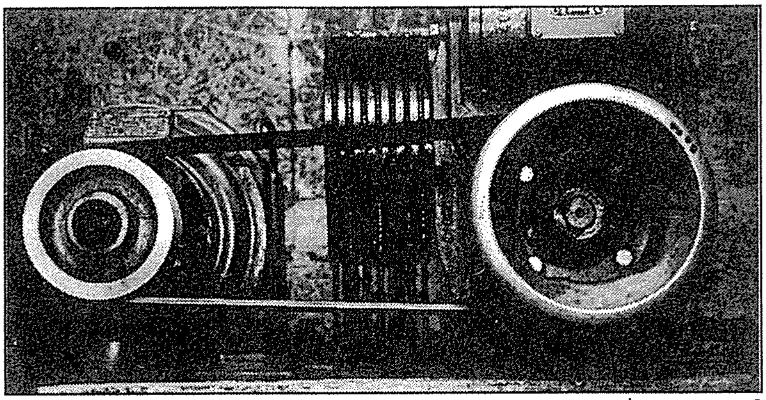


Figure 6

Linking the motor and gear by a V-belt did in fact have other engineering benefits. It became possible to mount the brake on the side of the worm gear so that it interlocked with the traction sheave, thus fulfilling one of the important demands in the safety codes. It was also possible to use the pole-changing motor, in common use at that time, with a given output and with prescribed inertial masses in conjunction with a gearbox of specified transmission ratio for elevators having different contract loads and speeds, and this merely by changing the transmission ratio of the V-belt.

2.2 The V-belt as one stage of a multi-stage main drive system

Increasing the transmission ratio on the V-belt side enabled the traction sheave side to be equipped with a less expensive, low-ratio spur gear. Figure 7 shows this type of a system for a 3-t freight elevator. Since safety codes require the brake to be mounted on the side of the second stage, a substantially larger braking torque is needed, which raises the cost of the brake.

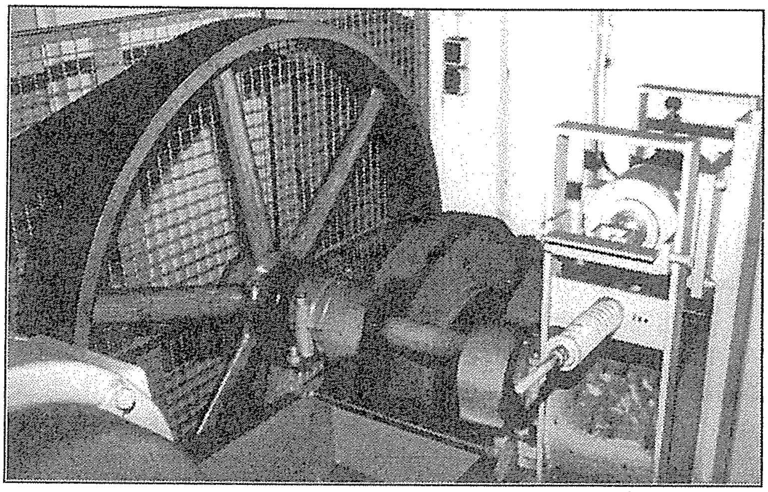


Figure 7

This arrangement - quiet-running V-belt drive on the motor side, spur gears on the traction side - was included in escalators designed by Herker and mass-produced by various companies in succession for many years. At the time these escalators were employed primarily in department stores, and the main argument for their use was the low operating noise of the V-belt drive. The major problem, though, was the arrangement of the brake: for reasons of cost and space the service brake was mounted on the motor side, consequently it could be made relatively small. An additional brake was intended to activate if the V-belt snapped. This was designed to act directly in the grooves of the large V-belt pulley, via a pivot, when placed under load. Whether this arrangement led to operating problems or whether the requirements of the inspection authorities became stricter, demands were increasingly made for an additional brake on the power take-off shaft, which made the drive system substantially more expensive. A growing number of less expensive toothed gears with low operating noise resulted in the manufacture of this V-belt drive system being discontinued.

3. Elevator systems exclusively based on V-belts

The problem of the brake has also been the greatest obstacle to all passenger elevators which use V-belts exclusively. I only know of two elevator companies that have built such drive systems over any length of time or are still building them.

3.1 Two-stage V-belt drive systems

The firm of USTO from Enniger, near Münster, built a two-stage V-belt drive system for small freight elevators. As Figure 8 shows, this system is similar to that of a door operator.

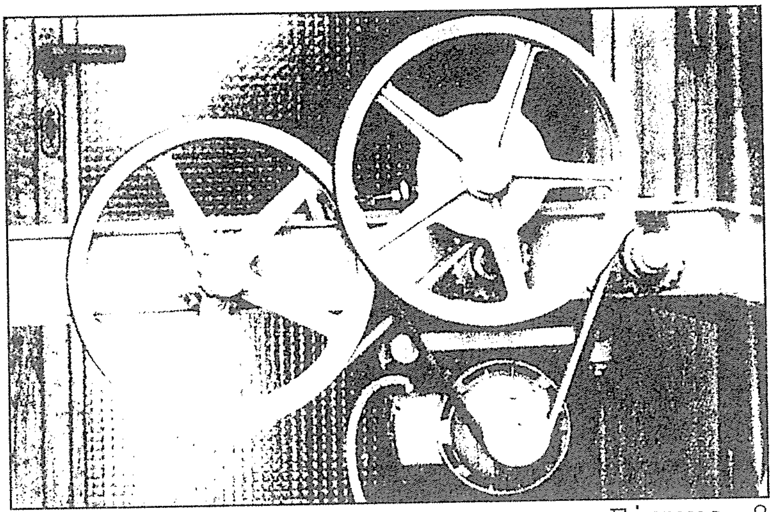


Figure 8

The safety code for small freight elevators, TRA 400, does not stipulate an interlocking connection between the brake and traction sheave - or in this case the traction chain wheel. USTO's drive system failed on another formality: the old version of TRA 400 demanded at least 5 V-belts (per stage) - now only 3 are required, to match the needs of small freight elevators.

The firm of Koch in Hamburg has been manufacturing passenger elevators with V-belt drives continuously since 1954. The systems generally have only one stage, although some 2-stage V-belt drives were constructed. For the sake of completeness I include a photograph of one of these drives (Figure 9). The large V-belt pulley for the second stage also acts as the traction sheave, with the cables running in the centre of the sheave between two sets of V-belts. The car and counterweight are suspended in a 1:1 ratio. Two elevators with this type of drive system have been operating day and night without interruption since 1978 in the premises of a publishing company, over 2,400 journeys were counted in 24 hours!

Two-stage V-belt systems as the main drive mechanism suffer from the same technical problems as when used for door operators: substantially greater torques have to be transmitted in the second stage. USTO solved this problem in the same way as illustrated in Figure 2: a greater number of V-belts with the same profile were used for the second stage. The two-stage drive systems manufactured by Koch employed both a greater number of belts and a larger belt profile in the second stage, in order to transmit the required torque.

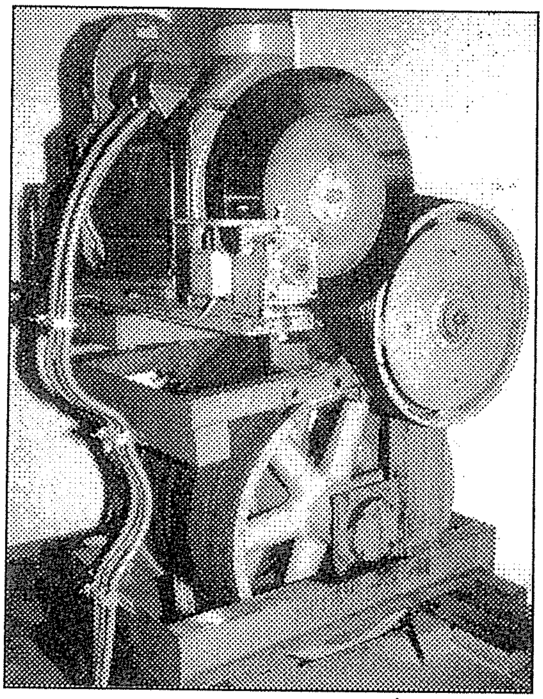


Figure 9

3.2 One-stage V-belt drive systems

Koch of Hamburg built their first V-belt drive system more than 40 years ago, many changes and refinements have taken place over the course of time.

Figure 10 - taken from a 1976 issue of the magazine "Elevator World" - shows the main features of this drive, which have remained unchanged up to the present day: power transmission from motor to traction sheave is effected by a one-stage V-belt drive, the operating brake is located on the motor shaft, the motor is mounted on a pivoting rocker. The weight of the motor maintains the belt tension and activates the additional emergency brake in the event of belt failure.

Of the many changes that have taken place since 1976 I wish to mention but a few: mounting of the traction sheave on roller bearings; reduction in the diameter of the drive sprocket and lower number of belts employed owing to a new belt design; V-belts positioned on one side; selected use of external rotor motors; inclusion of a control system (first ACVV, then VVVF) accompanied by a lowering of the inertia on the motor shaft; etc..

Thousands of such drive mechanisms have been installed in the north of Germany, in the area covered by Koch. The contract loads of elevators fitted with this drive range from 300 to 5000 kg. As long ago as 1973 several V-belt elevator drive systems were built with speeds of 3.5 and 4 m/s.

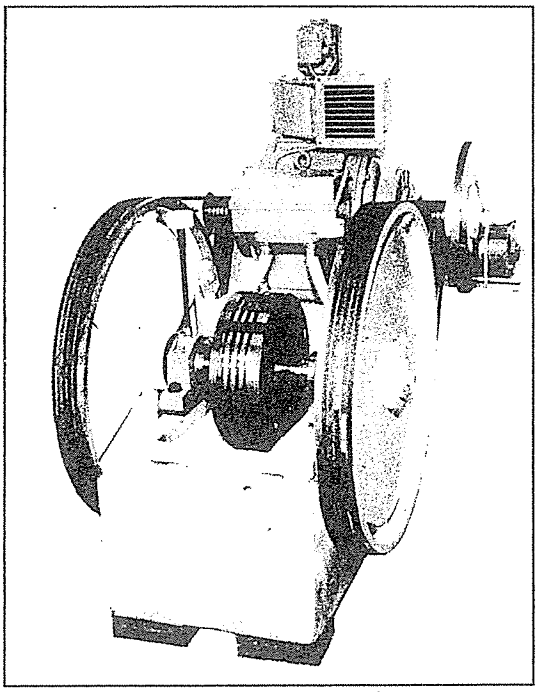


Figure 10

4. The modern V-belt drive

Building on my many years of experience with Koch in Hamburg, I have altered the V-belt drive in two essential features:

1) The brake has been transferred from the motor shaft, it now acts by interlocking with the traction sheave. It thus fulfils the requirements contained in the safety codes TRA 200 and EN 81, Part 1. This has the added benefit of greatly reducing the inertia on the fast-running motor shaft.

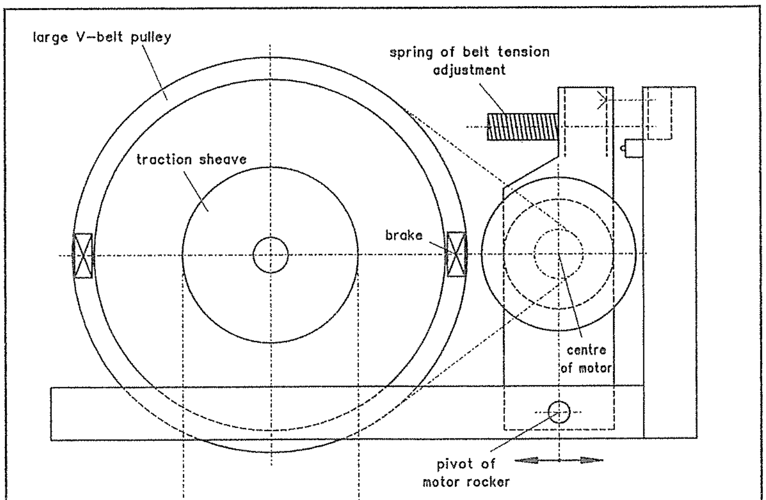
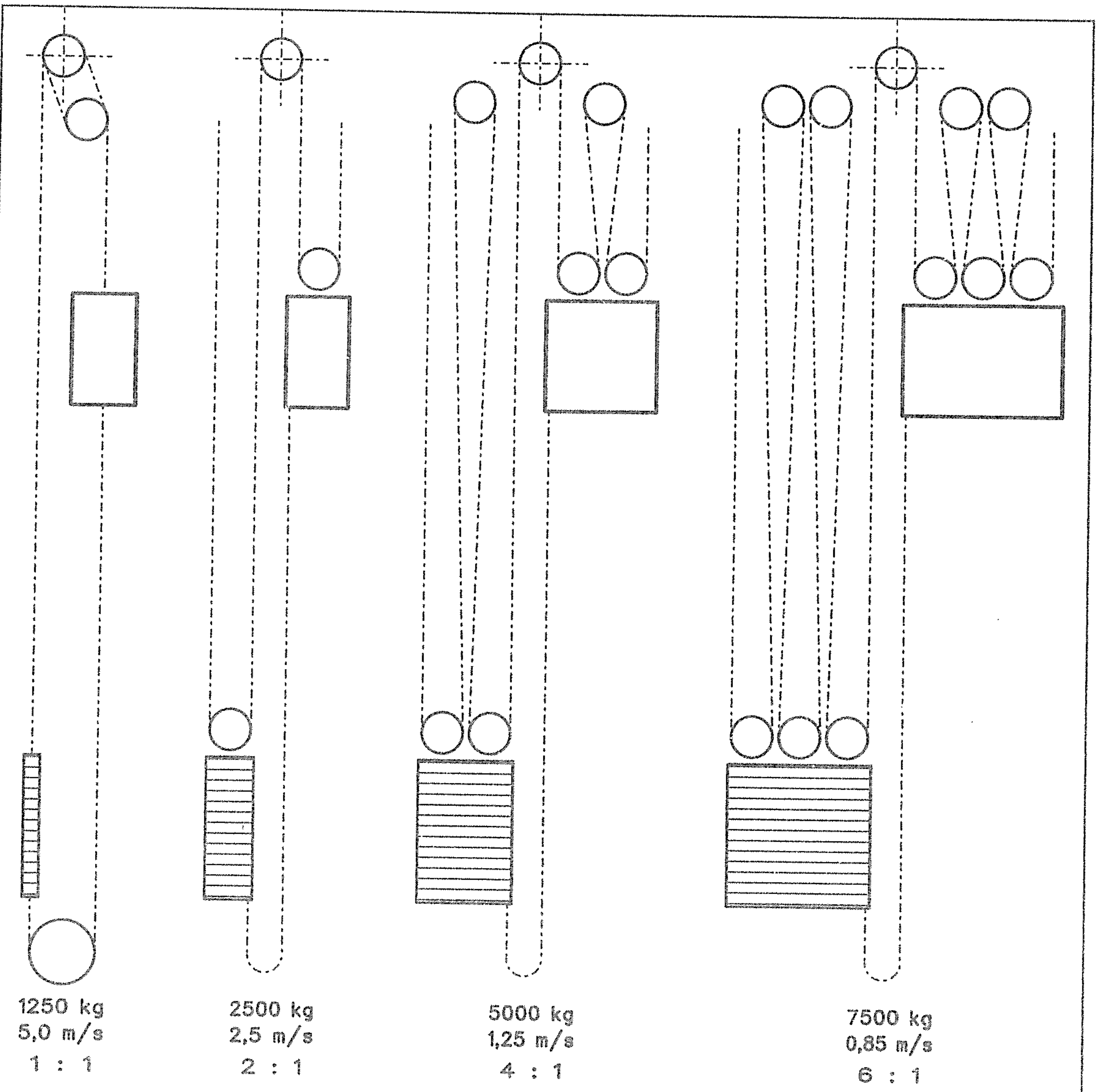


Figure 11

2) The belt-tensioning mechanism has been changed so that it is independent of the weight of the motor and the machine's direction of rotation. Belt-tensioning can be performed by any elevator technician who has received simple instruction, and can easily be inspected by safety authorities.

Figure 11 (an extract from my patent) clearly demonstrates these alterations.

The improvements mean that it is now even possible to sell this machine to elevator companies that have no prior experience of this particular drive system. Furthermore, removal of the previous design problems has been seen to open up a considerably greater range of applications. Investigations have shown that it is technically possible, without any major difficulties, to construct V-belt drive systems for contract loads of 2500 kg at a speed of 10 m/s or 15000 kg at 1.0 m/s.



Elevators with identical rope speeds and identical torques on the traction sheave

Figure 12

Since the V-belt drive, owing to its construction, has only a limited transmission ratio, part of this is transferred to the elevator roping system. This has been made possible by the use of polyamide cable pulleys with roller bearings, without incurring any great losses in power. Figure 12 provides a diagram of how the same drive system (with minor adjustments) can be used for a range of different elevators.

In these times of energy and cost consciousness, its 98% efficiency and use of low-loss and inexpensive four-pole motors make the V-belt drive a particularly interesting technical solution when compared with all other elevator drive systems.

Compared with worm gears the advantage is to be found on the side of the gear [1].

In comparison with gearless machines the advantages lies on the side of the motor, and even the use of modern frequency control systems does not alter this fact. Because of the lower rotational speed achieved by larger pole numbers and/or lower control frequencies, gearless machines require a significantly higher motor torque for the same output, which in turn demands a much larger and more expensive motor. In addition, the laws of physics dictate that low-speed motors have a lower efficiency, which can only be improved by an additional increase in motor volume.

Compared with highly efficient toothed gears (helical and planetary gears), the V-belt drive again has advantages: it generates little noise and, even over a 40-year operating life, neither becomes louder nor loses efficiency.

Concluding Remarks

In this lecture I have consciously avoided entering into great theoretical depth. This information together with the calculations for V-belts can be found in the lecture I gave at ELEVCON'93 in Vienna [2].

I have instead tried to give a general view of the practical solutions involving V-belts that I am familiar with. All these solutions are actual examples taken from practice and the photos are of elevators that have been in service for decades. They prove that the V-belt is a reliable machine element.

Practical evidence cannot be manipulated. Many solutions are modern one day and forgotten the next, and in the long term only the really good solutions become established. The V-belt has long since proven that it belongs to the good solutions where door operators are concerned, and the modern V-belt drive system for elevators can expect to join this "Hall of Fame" in the near future.

References

[1] *"Designing for reduced elevator energy costs"*
R. Stawinoga, lecture given at LifTech'94 in Brussels
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[2] *"New mechanical solutions for highly efficient gears"*
R. Stawinoga, lecture given at ELEVCON'93 in Vienna
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About the author

Roland Stawinoga was awarded the degree of Dipl.-Ing.(FH) with distinction in Mechanical Engineering from the Rheinische Inginieurschule in Bingen-on-the-Rhine, Germany in 1962. His many years of experience in the elevator industry started with an apprenticeship served at his father's company and include senior technical positions with a number of firms, the most notable of these being a period of 7 years with MAN in Gustavsburg, where he initially headed a design group for heavy goods elevators and later was in charge of escalator design. In 1973 he moved to Hamburg to take charge of the Technical Department in the firm of Gustav Ad. Koch, before finally assuming the role of technical advisor to the management in the latter period of his 17-year employment. 1990 saw the founding of his own engineering company, where fully equipped with the latest CAD technology, he designs elevators to meet the most sophisticated technical and optical requirements. His in-depth involvement with the V-belt drive for elevators has convinced him of its benefits, and he is currently engaged in developing and refining this system.