NEW MECHANICAL SOLUTIONS FOR HIGHLY EFFICIENT GEARS

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Summary

Traditionally, worm gears are used for lift speeds up to 1.6 m/s. There is also the possibility to use multiple thread worm gears for speeds up to 2.5 m/s. New developments include teeth gears and planetary gears. This paper describes an unconventional solution of a V-belt driven machine.

With the aid of standards relating to V-belt drives, the paper then describes the design requirements for their use in elevator machines. Finally, a comparison of the features of V-belt and conventional machines helps to highlight the applications in which V-belt drives can provide a cost-effective and convenient solution.

1. Introduction

There are two fundamentally different types of mechanical drive systems for elevators to be found in the specialist literature as well as in the minds of most elevator engineers: worm gears are used for speeds up to 1.6 m/s - elevators with high operating speeds (2.0 m/s and above) employ gearless d.c. motors. Worm gears have been employed in elevator construction since the introduction of electric single drives due to their high transmission ratios and low operating noise. Since the introduction of the traction sheave gearless motors have been the general standard for high speeds; however, they are considerably more expensive.

In recent decades new aspects have come to the fore which call for a critical consideration of existing gear concepts:

> In the medium height range (up to approximately 60 m), which is particularly common in European cities, one of the approaches used for raising the handling capacity is to increase the operating speed. Speeds of up to 2.5 m/s are increasingly in demand.
>
> Variable-voltage control (VV) for a.c. motors has become generally established in elevator construction. This technique enables speeds of up to 2.5 m/s to be achieved. The introduction of microprocessor technology has also resulted in an increase in the use of variable-frequency control (VF). Although this is in fact more expensive, it can be used for higher speeds too, instead of the d.c. control previously employed.

The manufacturers of traditional elevators are making efforts to incorporate these new developments:

Many manufacturers of worm gears are already able to offer excellent quality gears for speeds of 2.5 m/s. There are a large number of measures for achieving this: enhanced materials, new designs for the tooth flanks, improved quality, new production methods and better testing facilities in the manufacture of the gearing, multi-threaded worm gears (double and triple-threaded), use of roller bearings instead of friction bearings, improved lubrication by means of synthetic oils,...

Conversely, there are also efforts to adapt the gearless elevator drives to these new possibilities. And for some time now they have been provided with variable-frequency control. Attempts have been made to reduce the price of this drive by means of a less expensive mechanical design (Blocher Dresden, BORAL Australia).

However, there are also several developments that are trying to adopt an entirely new approach. It is logically assumed that the prime reason for worm gears being employed in elevator construction is that they have a high transmission ratio by nature of their construction. These new developments are used in an attempt to avoid further disadvantages of worm gears (e.g. wear on the flanks after long periods of service, unfavourable degree of efficiency, high "pull-out" coefficient of friction). Reduction in costs is of course one of the other aims:

The Japanese firm Mitsubishi is employing helical spur gears in conjunction with four-pole, variable-frequency control a.c. motors for the range from 2 m/s to 4 m/s. Due to their unpleasant operating noises at high rotations, spur gears had seldom been used in elevator construction and then mostly for goods elevators. Enormous technical effort has been invested in these new spur gears in order to overcome the noise problem. The result is a less costly alternative to the gearless motors that are otherwise used for this speed range.

Another technically outstanding achievement is the development by the company Zahnradfabrik Passau of a planetary gear for elevators with operating speeds of up to 2.5 m/s (to date). This has also provided remarkable success in solving the noise problems of spur gears. Furthermore, the planetary gear is of a compact construction and requires significantly less space than the worm gear. The efficiency of 98% means that considerably lower motor outputs are required.

Since 1954 the elevator company Koch in Hamburg has been employing belt drives for elevators. Again this type of drive has a very high degree of efficiency and, by reason of its design, it is also extremely quiet. This type of elevator machine is still being produced, and in Hamburg and the surrounding area thousands of them are in opration. From 1973 to 1990, while holding a senior technical position within the company, I was involved in the further development of this drive. Since founding my own engineering office, I have used my experience of this drive system to develop a completely new principle for belt drives in elevators, which also includes conformity with EN 81.

2. V-Belt Drive for Elevators

The V-belt is a machine component that has been subject to continual development since its invention in the 20's. The properties of V-belt drives are described as follows in the draft VDI guideline VDI 2578:

- simple design
- low weight
- compact construction
- ease of assembly
- ease of interchangeability
- damping of fluctuations in load
- low costs
- low maintenance requirement
- can be used in areas with an explosive hazard

These properties resulted in V-belts being continually used in the construction of elevators and escalators. The most familiar use was as a connection between the motor and worm gear (acting as a clutch) to achieve better alignment of the motor in confined spaces. In escalator construction a two-stage drive had been used for decades. Its first stage was a narrow V-belt (wedge belt) drive and the second slower stage a helical spur gear. USTO, a little elevator company from Enniger near Münster, built a two-stage belt drive for small goods elevators over a long period.

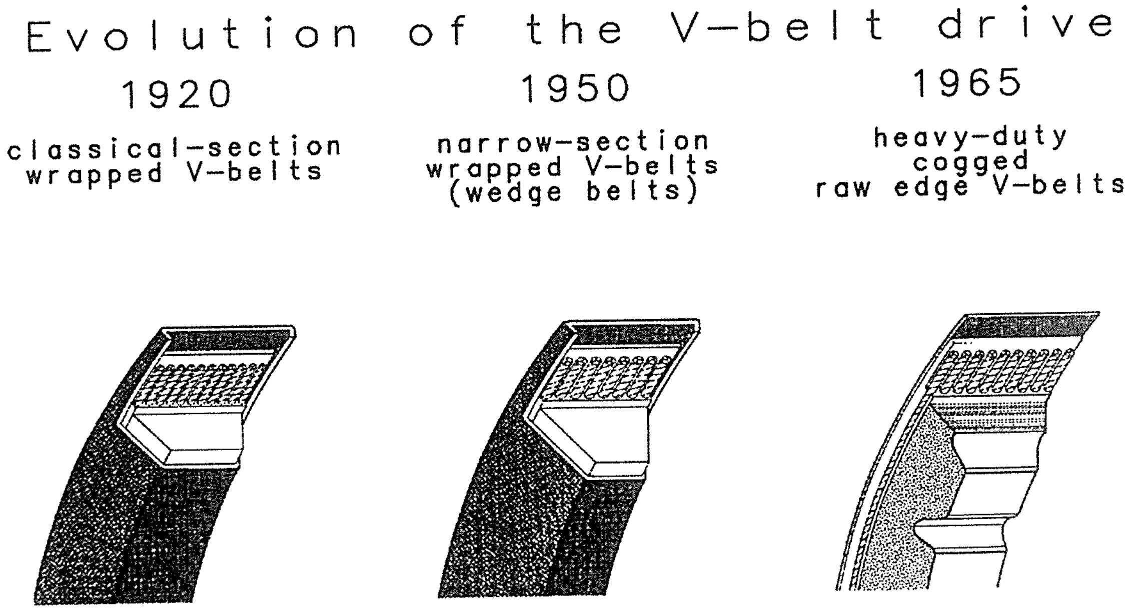

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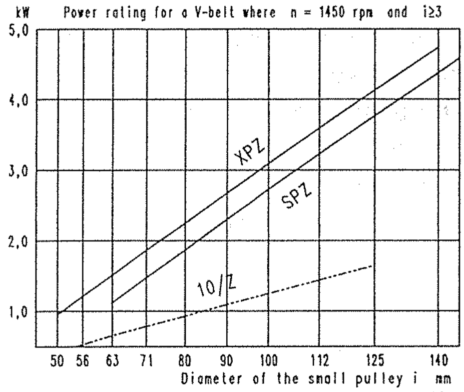
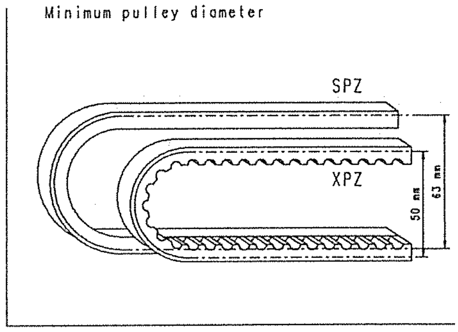
Fig. 1

By continual further development (Fig. 1) it has been possible to transfer ever-greater power ratings with V-belts (Fig. 2). Originally, the elevator drives were constructed with the classical-section wrapped 10/Z-profile V-belts in accordance with DIN Standard 2215. Subsequently, 19 V-belts were needed for an elevator with 1000 kg contract load and a speed of 1.0 m/s (design in accordance with TRA 226.1 [Technical Regulations for Elevators] - technical data for V-belts based on information provided by ContiTech). When it then became possible to use wrapped SPZ profile narrow V-belts (wedge belts), only 13 belts were necessary for the same dimensions and conditions. Using the latest V-belt design, the heavy-duty raw-edge cogged XPZ V-belt in accordance with DIN 7753 Part 1, the number of belts required for the same drive is reduced to 10. At the same time this new V-belt design permits the use of smaller minimum pulley diameters (Fig. 3). Higher transmission ratios thus become possible, and the lower bending force required leads to higher efficiency, given as 98% by the manufacturer. The lower number of belts and the reduction in diameter bring about considerable savings in cost and space. Hence, unbeknown to the elevator specialist, a development has taken place which has resulted in the V-belt becoming more and more interesting as a machine component.



ContiTech Fig. 2



ContiTech Fig. 3

3. Standards for V-belts - V-belt calculation

Dimensions and calculations for V-belts are expressed according to the same system in all of the standards at my disposal (DIN 7753 Part 2, BS 3790, RMA/MPTA IP-22). Since I am most familiar with the German standards, I shall use their formulae in this section. The calculation itself is one of life expectancy. The power ratings and factors given in the standards are general values which are continually being updated by the manufacturers concerned. In general, the power ratings and factors quoted by manufacturers are for a life expectancy of 25000 hours. The following values can be taken from the standards or corresponding manufacturers' tables:

Power rating P_R in kW	a function of the type of V-belt, the effective diameter of the small V-belt pulley, the speed of the small pulley and the transmission ratio;
Arc of contact factor c_1	a function of the arc of contact around the small pulley;
Service factor c_2	a function of the type of drive unit and the daily service period;

Length correction factor c_3 a function of the effective length of the V-belt;

The number of belts required to transmit a power P in kW is then calculated as:

$$z_{er} = \frac{P * c_2}{P_R * c_1 * c_3}$$

The standards also contain a lot of important information on dimensions of the belt profiles and belt pulleys, calculation of the distance between axles, notes on belt tension and how to test it; however, a detailed examination of these points is far beyond the scope of this study.

4. Elevator safety codes and V-belts

Of far greater importance when using V-belts for elevators are the requirements of the elevator safety codes. Presumably, due to the relative lack of experience with this machine component, large differences exist:

EN 81 Part 1 - 12.2.2

> "Use may be made of belts for coupling the motor or motors to the component on which the electro-mechanical brake operates. A minimum of two belts shall be used."

TRA 200 - 226.1

> "In the case of V-belt drives at least 5 belts must be used which have been measured in accordance with DIN 2215, 2217 and 2218 or in accordance with DIN 2211, DIN 7753 Part 1 and Part 2 or equivalent documentation. Even if one of the V-belts should fail, the service factor of $c_2 = 1.6$ (DIN 2218 and DIN 7753 Part 2) must be maintained."

ASME/ANSI A17.1a - 208.9

> "208.9a Belt and Chain Drives: Indirect-drive machines, utilizing V-belt drives, tooth drive-belts, or drive chains, shall include not less than three belts or chains operating together in parallel as a set. Belt and chain drive sets shall be preloaded and matched for length in sets.
>
> 208.9b General Requirements: Belt sets shall be selected on the basis of the manufacturer's rated breaking strength and a factor of safety of 10. Chain and sprocket sets shall be selected on the basis of recommendations set forth in the Supplementary Information section of ANSI B29.1, using a service factor of 2.0. .... Load determination for both the belt and chain sets shall be based on the maximum static loading on the elevator car, which is the full load in the car at rest and at a position in the hoistway which creates the greatest load, including either the car or counterweight resting on its buffer.

Chain drives and belt drives shall be guarded to protect against accidental contact and to prevent foreign objects from interfering with drives.

208.9c Monitoring and brake location: Each belt or chain in a set shall be continiously monitored by a broken belt or chain device which shall function to automatically interrupt power to the machine and apply the brake in the event any belt or chain in the set breaks or becomes excessivly slack. The driving machine brake shall be located on the traction sheave or drum assembly side of the driving machine so as to be fully effective in the event the entire belt set or chain set should break."

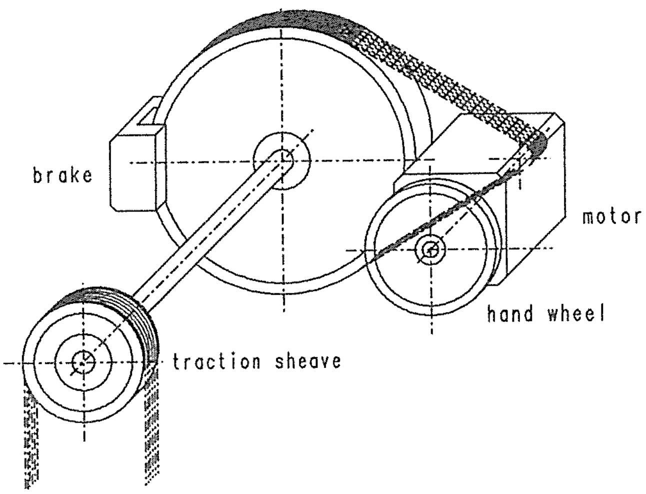
Since no other more detailed regulations are given, I would interpret EN 81 as meaning that the minimum of two belts have to be dimensioned in accordance with the relevant standards. In my estimation a service factor of $c_2 = 1.2$ would have to be applied, which allows for medium-duty operation over a maximum of 10 hours per day.

A German inspector who regularly consults his copy of the TRA, would certainly have problems with this layout, since the TRA demands at least 5 V-belts, one of which may not be included in the calculation and a service factor of $c_2 = 1.6$, which is equivalent to a heavy-duty rock crusher operating for 16 hours a day. (It should be added that these regulations also apply to small freight elevators! - which resulted in the company USTO halting production of V-belt drives.) - The consequence of adopting this obviously excessively high safety level is that the theoretical life expectancy of 25000 hours is greatly surpassed. Since even an elevator that is used very frequently has an effective service time of approximately 3 hours per day respectively 1000 hours per year, the V-belts would in theory last far longer than the elevator itself. This contrasts sharply with the figures from belt manufacturers, who give a life expectancy for the belt - which is largely made of rubber - of some 10 years. Practice shows, however, that the V-belts can in fact last the entire lifetime of an elevator. Any failures have always been due to other causes (incorrect tension, unequal belt lengths within the set, mechanical damage, etc.).

I personally find the requirements of the American elevator rules even somewhat more difficult to understand. Although there are standards in the USA which are tailored to the special properties of the V-belt and which take account of all the experience with this machine component, the belt is treated as a chain. Description of the belt refers to a rated breaking strength, which is to be found in neither any standard nor any printed manufacturer's documentation. With a factor of 10, the safeguard against breakage is 5 times higher than that for a chain. The maximum load to be applied (car weight and contract load plus an additional force arising occasionally when the counterweight comes to rest on the buffer) still gives a safety factor far in excess of 10 for normal operation. - After having found out the breaking strength from a belt manufacturer, I performed a calculation for a special case on the basis of this American standard and observed that the result was in approximate agreement with the TRA. Nevertheless, this American standard which takes no account whatsoever of the special characteristics of V-belts is in my opinion very unsatisfactory.

5. Design of the V-belt drive

The modern V-belt drive consists of two shafts, which are directly connected with one another by V-belts with a one-stage transmission. Both shafts are fitted with low-noise roller bearings. Located on the low-speed shaft are the traction sheave, the large belt pulley and the service brake, whereas the high-speed shaft accommodates the small belt-driving pulley and the motor (see Fig. 4 for a schematic representation). It is usually powered by an inexpensive 1500-rpm a.c. motor. The preferred arrangement is for an overhung traction sheave, which can also be aligned directly in the hoistway by a simple extension of its own shaft. This enables the machine to be arranged in any desired relationship to the hoistway (Fig. 5).



Schematic representation of the V-belt drive for elevators

Fig. 4

This simple arrangement has many benefits:

- outstanding efficiency, hence lower power rating of the motor (cost savings on motor and energy - due to the smaller size of motor, there is less "dead" mass on the high-speed shaft, an additional energy saving)

- particularly low operating noise can be achieved with relatively low production costs

- no parts to wear out: roller bearings are lubricated for the entire life span of the machine, V-belts are similarly calculated to last the for the whole working life (in the unlikely event of replacement being necessary, only low costs are involved).

- low maintenance costs (for the same reasons)

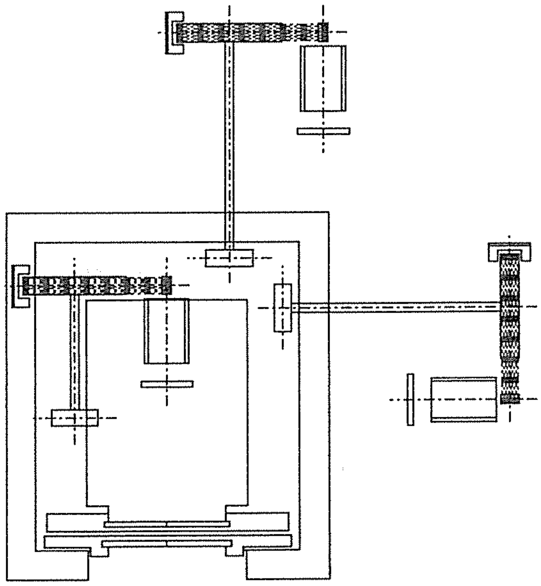
- the machine has a modular construction, a compact set of components enables the entire operating range to be covered from 320 kg to 5,000 kg and from 0.5 m/s to 4 m/s. This operating range is a reflection of the applications to date and can be extended.

- low setting-up and production costs; even with relatively limited means, it is possible to construct a high-quality elevator machine.

- each of the shafts has two sets of bearings (not a statically indetermined system)

- both shaft systems are constructed on a common basic frame so that no additional support frame is needed.

- low weight and the ease of dismantling the machine into its individual moduls (traction sheave, motor shaft and basic frame) mean that transport and assembly are straightforward.



Mounting options for the V-belt elevator machine

Fig. 5

6. Discussion

Hence in a comparison with planetary gears, V-belt drives are seen to have some advantages. V-belt traction also has some features that may appear detrimental at first sight:

The first of these is the inherent slippage in frictional drives. Now, this slippage is a normal phenomenon in traction sheave elevators and is merely increased by the use of a V-belt drive. In terms of safety, this is of no significance, since in line with elevator safety codes, the brake is fitted to the shaft of the traction sheave. As the tacho-alternator or pulse generator required for control is usually located on the motor shaft, substantial discrepancies between the theoretical curve and the effective curve of the elevator car might result, as is the case with all traction sheave elevators. Consequently, this difference should be inspected more frequently and corrected if necessary.

Due to the transmission ratio required for elevator operation the large V-belt pulleys have a relatively large diameter. This has to be taken into account in making allowance for the space required by the machine, before all when the machine is placed above the hoistway. A recess in the wall of the machine room may be necessary. If the machine is located next to the hoistway, however, the design of the machine enables extremely small machine rooms to be employed.

The production input for a V-belt traction drive is the same regardless of whether the drive has a 5 kW or a 50 kW motor. In the case of low power ratings it can therefore be seen that the V-belt drive is barely able to compete with the more inexpensive series-produced worm-gear drives. I will now present some examples of applications where the V-belt traction drive is superior to other drives, either for reasons of cost-effectiveness or design:

- for high-speed elevators, e.g. 1250 kg - 2.5 m/s
- for heavy-duty freight elevators, e.g. 5000 kg - 1.25 m/s
- for traction drives with a limited current consumption
- in elevators with restricted hoistway dimensions, e.g. 300 kg - 1.0 m/s, machine in basement position, low headroom (2:1 roping and small traction sheave diameter required)

The fact that a V-belt traction drive can even be produced economically as a one-off item gives it a great advantage over spur gears for elevators. The latter requires considerable investment even before the first traction drive can be produced. It can, however, be assumed that the production costs for V-belt drives can also be substantially reduced by larger batch sizes.

From the V-belt manufacturers' point of view this use of V-belts is also atypical. On the one hand, this concerns the high transmission ratio required, which calls for extremely long belts and results in relatively low arcs of contact on the small driving pulley. This particularly affects the operation of elevators with their frequent changes of direction and alternating phases of acceleration and retardation. Modern-day design of the V-belt elevator drive is therefore a result of many years of experience, accompanied by the occasional setback.

Conclusion

The use of highly efficient gears - and this also applies to spur gears - represents a challenge for the elevator engineer in examining the entire technical concept in terms of its energy savings. This results in a more fastidious layout of the counterweight and more frequent use of additional elements to compensate for the weight of the cables. It also leads to more consistent use of roller bearings in cable pulleys and of guide rollers or guide shoe gibs with better sliding properties. A more precise dynamic design taking into account the overall efficiency then also enables safety factors to be reduced. The result of all these efforts is higher quality of the elevator installation while at the same time achieving substantial cost savings by means of lower motor output and its consequences of lower electricity consumption, lower power supply rating, and hence smaller control and switching equipment.

References

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Biographical notes

As my father had a small elevator company in Wiesbaden, elevators became my destiny. I got a wide range practical education, including electric control and hydraulics, which began to be common in the German market during my early years. With the studies of mechanical engineering at nearby Bingen on the Rhine I gained a solid theoretical base. In the elevator division of MAN Gustavsburg, I became acquainted with the organization of a large scale enterprise and learned to make cost-concious equipment, becoming in a short time the leader of a construction group for heavy cargo elevators. When MAN began the production of escalators I took over the technical adaptation of the licence agreement. At the end of my 7 years engagement at MAN I was responsible for escalator construction. In 1973 I went to a senior position with Koch Hamburg. This middle sized elevator company has been known in Northern Germany for its high technical standard and I undertook the important role of proving to customers that Koch makes better elevators than other worldwide competitors. By 1990 - having more than 36 years of construction experience - I founded my own elevator construction office, utilizing the new technical possibilities (CAD). I now work for elevator companies, offering them my extensive know-how and engagements to make elevators of outstanding quality. My special passion is the construction and development of elevator drive systems.