XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

MEASURING THE ESCALATOR TRANSMISSION EFFICIENCY

P.J. Kral
Institute for Machine Elements and Machine Design
Vienna University of Technology
Getreidemarkt 9, A-1060 Vienna, Austria

Abstract: At the Institute for Machine Elements and Machine Design three different escalator (moving staircase) gearboxes were tested to compare their coefficient of efficiency. The tested gears are two worm gears and a bevel-spur gear. The two worm gears differ in its tooth shape (hollow flank – involute flank).

For this purpose a test bed consisting of gearbox, electric motor and regulated pendulum generator was built up.

To calculate the coefficient of efficiency it is necessary to measure the input- and output-torque at both gear shafts. First is done by measuring the effective power (2-Wattmeter Method) of the electric motor. The second value, the output-torque, could be controlled with aid of the brake generator and is exactly known.

The coefficient of efficiency of each gear is measured for both directions at idle, 25%, 40%, 50%, 75% and full load.

Keywords: Gears, Efficiency, coefficient of efficiency

1 INTRODUCTION

Efficiency of escalator gears is one of the main points to decide which gearbox should be used in practice [1, 2]. In most cases escalator gearboxes are worm gears but in some cases bevel or spur gears are also used. In order to compare efficiency of the test gears under same conditions with each other, a test bed (see section 3) was built up. To determine the connection between effective power and output-torque of the drive motor it was necessary to measure the motor characteristic line first.

2 PRETEST

2.1 Measurement of the motor characteristic line

As mentioned, for the determination of the efficiency, the electrical input power of the drive motor was measured. Therefore the knowledge of the connection between mechanical and electrical motor power was necessary. In this way the engine was jointed with a “Periflex”-clutch to an available direct current pendulum generator with torque measuring scale. The electrical power was measured with two wattmeters, the rotational speed with an optical rotation speed sensor. The result of the pretest, the motor torque characteristic line, is shown in figure 1.

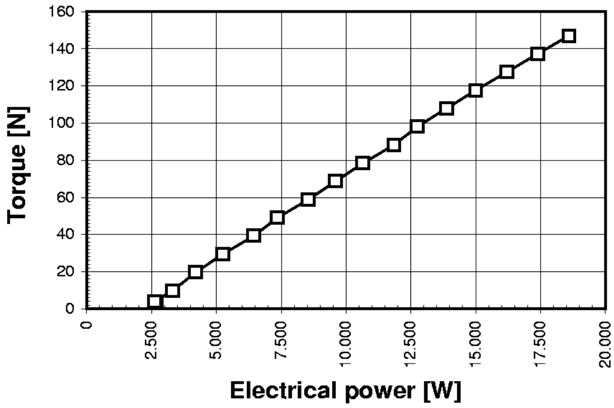

Figure 1. Motor characteristic line

3 TEST BED

The test bed for measuring efficiency of escalator gearboxes is shown in figure 2. The gearbox (1) is mounted on a stable steel frame. The electric drive motor (2) is directly flanged on the gear to guarantee the same configuration as in the real escalator. A chain gear (3) (speed ratio of 3:1) between gear and pendulum generator (4) reduces the output-torque and makes it possible to use the existent brake generator. The equilibrium of the pendulum generator is achieved by regulation (5) of its excitation current and therefore of its excitation field. The energy produced by the generator is converted into warmth by a resistor (6). To adjust the output-torque $\mathbf{T_{out}}$ exactly the generator is loaded by using weights (7). The effective power of the drive motor is measured with the 2-Wattmeter method (8). With these results the input-torque $\mathbf{T_{in}}$ is calculated out of the well-known drive motor characteristic, measured in the pretest series (see section 2). If an efficiency of the chain drive of η_C=0.98 is assumed, the transmission efficiency can be determined easily by using equation 1.

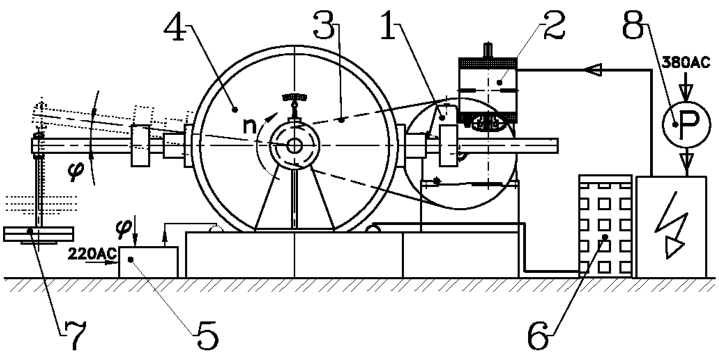

Figure 2. Equipment for measuring the transmission efficiency coefficient of escalator gears

4 DEFINITION OF THE COEFFICIENT OF EFFICIENCY

The coefficient of efficiency is defined as the output-power $\mathbf{P_{out}}$ divided through the input-power $\mathbf{P_{in}}$ of the escalator gearbox [3, 4]. The chain transmission between gear and brake generator is considered by the chain efficiency h_C. This shows the following equation 1.

$$\eta = \frac{P_{out}}{P_{in} \cdot \eta_C} = \frac{T_{out,G}}{T_{in} \cdot i \cdot \eta_C} \qquad (1)$$

η .... coefficient of efficiency of the testing gear
P_{out} .... output-power of the gearbox
P_{in} .... input-power of the gearbox (2-Wattmeter-Method)
$T_{out,G}$ .... output-torque of the generator (adjustable)
T_{in} .... input-torque of the gear (=output-torque of the motor, out of motor characteristic)
i .... gear ratio
η_C .... coefficient of efficiency of the chain gear, η_C=0,98

5 TESTED WORM GEARS

5.1 Worm gear with hollow flanks

Maximal power:	15 kW
Center distance:	a=160 mm
Number of teeth:	z_1=2, z_2=49
Gear ratio:	i=24.5
Axle modules:	m_a=5,27 mm
Flank form:	Cavex (ZC-worm)
Material of the worm:	case hardened, polished
Material of the worm wheel:	GZ-CuSn 12Ni

5.2 Worm gear with involute flanks

Maximal power:	15 kW
Center distance:	a=160 mm
Number of teeth:	z_1=2, z_2=49
Gear ratio:	i=24.5
Axle modules:	m_a=5,33 mm
Flank form:	Involute (British Standard)
Material of the worm:	SAE 8620 case hardened to 58-62 Rockwell C
Material of the worm wheel:	BS 1400, 1985 Grade PB2-C

5.3 Bevel-spur gear

Maximal power:	15 kW
Center distance:	a=131,20 mm
Number of teeth:	z_{11}=11, z_{12}=68, z_{21}=20, z_{22}=81
Gear ratio:	i=25.037
Flank form:	Involute
Material of the bevel wheel:	17CrNiMo6
Material of the spur wheel:	17CrNiMo6

6 RESULTS

In the tests, two worm gears with different flank forms (involute and hollow flank) were examined. Besides a bevel-spur gear was also tested as an alternative. All the gears were tested on the same test bed and in the same manner to receive comparable results (see section 3). In the case of these test bed experiments the gear efficiency, the maximum gear housing temperature, the occurring wear and the sound power level of the gearbox were measured [1]. But this article only discusses the measurement and the results of the gear efficiency.

In the following diagrams 2-4 the gear efficiency h, depending on the load step **L** (ratio of power to the maximum power, $(P/P_{max})*100$) is shown. Two lines are plotted in every diagram, because the efficiency of the test gears was measured in both senses of rotation. The measured gear efficiency of both directions of movement differs about 10%. Also see, table 2.

The maximum coefficient of efficiency could also be seen in figures 3a-3c.

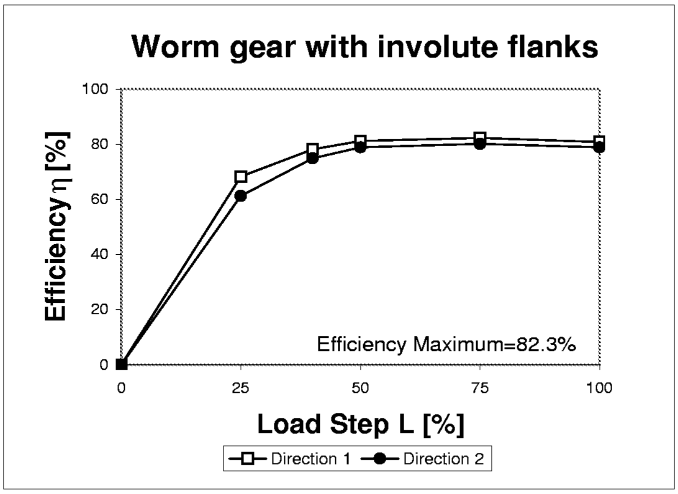

Figure 3a. Gear efficiency, measurement results: worm gear with involute flanks

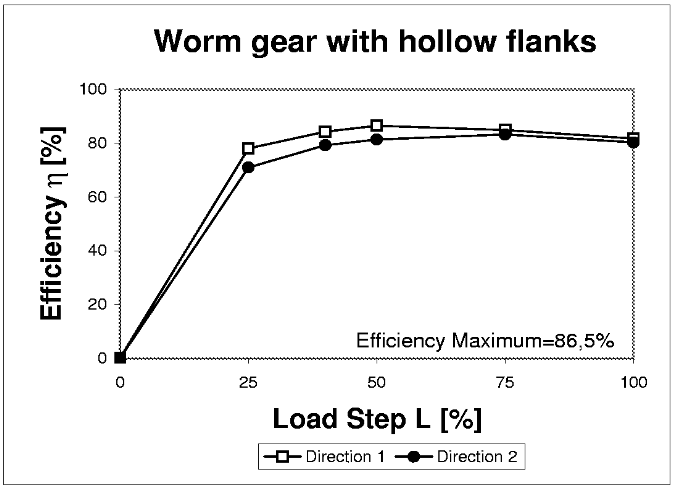

Figure 3b. Gear efficiency, measurement results: worm gear with hollow flanks

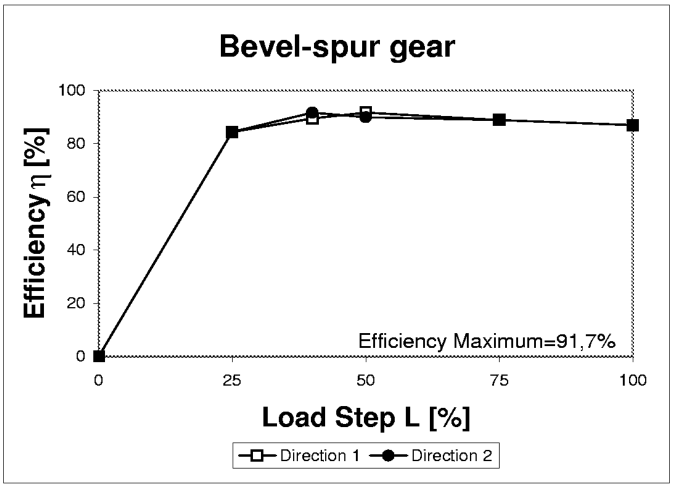

Figure 3c. Gear efficiency, measurement results: bevel-spur gear with involute flanks

Table 1 clearly shows the measured efficiency of the three gears in direct comparison. The values for rated power (load step=40%) are printed bold and italics in this table. All these coefficients of efficiency are average values. For idle speed (load step=0%), the gear efficiency is of course 0%. Therefore, the idle power in [kW], caused by friction (bearings, oil, gearing) is also noted in the table besides.

Table 1. Measurement values of the Efficiency of worm gears with different flank shape

Load step [%]	Coefficient of efficiency [%]		
	Worm gear Involute flank	**Worm gear** Hollow flank	**Bevel-spur gear**
0	1,20 [kW]	0,80 [kW]	0,25 [kW]
25	64,8	74,6	84,4
40	***76,5***	***81,8***	***90,6***
50	80,1	84,0	90,9
75	81,2	84,4	88,9
100	79,9	81,1	87,0

Table 2. Difference of the coefficient of efficiency between both directions

Load step [%]	**Difference of the coefficient of efficiency [%]**		
	Worm gear Involute flank	**Worm gear** Hollow flank	**Bevel-spur gear**
0	0,0	0,0	0,0
25	10,4	9,1	0,0
40	***4,1***	***5,9***	***2,5***
50	2,8	5,9	1,9
75	2,7	1,9	0,0
100	2,4	1,8	0,0

7 SUMMARY

The results of the gear tests show that the coefficient of efficiency depends on the load step (and thus the input power of the gearbox), the sense of rotation, the construction of the gear and particularly the shape of the tooth flanks.

Maximum efficiency is reached around load step 50 %. This is really good because the rated power of the gears is 40 %, at this load step the gear is running most time. The diagrams also show that the efficiency difference between both directions is not so big, especially in the rated power field.

The influence on the efficiency depending on the design of the gearbox could be seen in figure 4. The bevel-spur gear brings up the highest coefficient of efficiency, the worm gear with the hollow flank delivers about 5 percent more efficiency in comparison to the worm gear with involute flanks, but about 5 percent less in comparison to the bevel-spur gear. But gears used in moving staircases must also be as quiet as possible. Worm gears are normally quieter than other gears for example the bevel-spur gear. With these results the worm gear with hollow flanks was the optimal escalator gearbox, because of its good efficiency and excellent noise levels.

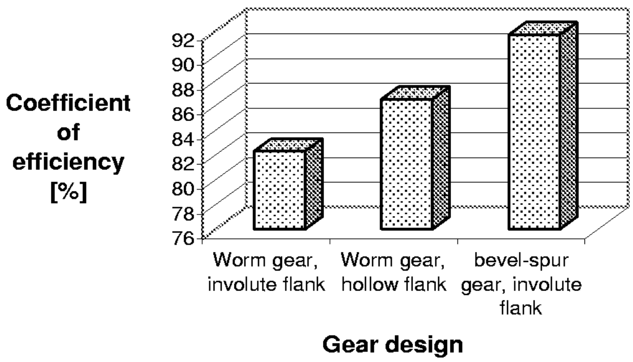

Figure 4. Maximum efficiency depending on the design of the gears

REFERENCES

[1] L. Rinder, P. Kral and S. Pausch, Rolltreppengetriebe im Vergleichstest, *Gedenkschrift Prof. Beitz*, Springer Verlag, 1999.
[2] S. Pausch, Verschleiß von Schneckengetrieben-Theorie und Praxis, *Dissertation*, Vienna University of Technology, 1998.
[3] G. Niemann, *Maschinenelemente Band II*, Springer Verlag, Berlin, 1985.
[4] G. Niemann, *Maschinenelemente Band III*, Springer Verlag, Berlin, 1986.

AUTHOR: Univ.-Ass. Dipl.-Ing. Dr. Peter J. Kral, Institute for Machine Elements and Machine Design, Vienna University of Technology, Getreidemarkt 9, A-1060 Vienna, Austria
Phone Int +43 1 58801/30614, Fax Int +43 1 58801/30699, E-mail: peter.kral@tuwien.ac.at.