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GEAR PUMP DESIGN: OPTIMIZATION FOR DELIVERY INCREASE

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1. Summary

This paper takes into consideration the results of a previous study concerning the influence of each singular toothing parameter on gear optimization.
Then, it examines the analytical procedure for developing the interactive variation of those parameters.
Finally, the results obtained through the abovesaid interactive variation and those of our previous study are compared.

2. Symbols

a'	operating center distance	n_1	speed of the drive gear
b	face width	r_a	outside radius
h_0	nominal addendum of the tool	x	shift coefficient of the toothing
j_p	backlash at the pitch diameter	z	number of teeth
j_r	head clearance	C	capacity per turn
k	addendum reduction	α_0	pressure angle
m_0	tool's modulus	ε	face contact ratio

Subscripts 0, 1 and 2 used in the text refer to the tool, gear 1 (driving) and gear 2 (driven) respectively.

3. Introduction

Research studies on the minimization of the weight and dimensions of gear pump, on equal materials and performance, are conducted at the international level.
The reason for this is an increasing trend in the production of gear pumps, especially in the automobile and industrial sectors.
The studies conducted in the past allowed us to gradually improve performance over the years; a significant improvement (approx. 20% increase) was achieved by the authors of this study by hypothesizing the design of a hydrostatic unit (gear pump) and by assigning the two gears that make up the gear unit a gear ratio other than 1, the optimal value of which is determined each time.
Other minor improvements have been achieved by studying the influence of small variations in the center lines, pressure angle and module, obviously also extending beyond the standard values; these small improvements were obtained by evaluating the influence that each single parameter (operating center distance, pressure angle, modulus) has on the optimization of a gear with a gear ratio other than 1.
In this way, on top of the more than 20% improvement mentioned above resulting from the gear ratio

optimization and the ratio being different from 1, there is a further improvement which is, however, quite insignificant; in fact, we are talking about only a few units per hundred**.**
According to the aforementioned, the best way to significantly improve performance on units of equal weight and dimensions is to treat the *interactive variation* among the numerous parameters characterizing the gear pair; in this respect, the influence of gear ratio variability, in terms of the overall and complete interactivity with the other parameters, is also studied.

4. Analytical study

In our search for new and significant improvements, we have provided an analysis of the contemporary variation procedure – always within the preset limits – for operating center distance, pressure angle and modulus.
In this respect, it is evident that we need to optimize each single constructive solution corresponding to any potential combination of the above-mentioned parameters.
The calculation program created specifically for this purpose allows us to perform the abovesaid optimization in a very short time.
In order to simplify the quantitative evaluation of the results, the optimization proposed in this study makes reference to the same gear[1] considered in previous studies; obviously, the proposed optimization criterion can be applied, without distinction, to any other gear pump designed for primary and secondary hydrostatic units.
In the case under examination, the adoption of an optimized gear ratio other than 1 (z_1 = 12, z_2 = 8) made it possible to obtain a theoretical increase in the displacement/revolution (C = 5.604 $cm^3/2\pi$) equal to 19.26%.
In this study we have examined the effects of the principal toothing parameters' interactive variation (a', α_0, m_o), assuming a variation range for each one of them equal to ±10% versus the corresponding values identified in the optimization work conducted in the previous study; the application of such criterion made it possible, thanks to the abovesaid calculation program, to identify more than 800 realizable constructive gear solutions[2].
Among these solutions, the maximum displacement/revolution is obtained for gears with the following specifications: a' = 33.40 mm, α_0 = 21°, m_o = 3.20 mm.
Table 1 below also shows other parameters characterizing the sized toothing and interactive optimization.

Table 1. Gear drawn through interactive optimization of the parameters m_0, a_0, a'

m_0	3.20 mm	z_2	8	k_2	-0.03
α_0	21°	r_{a1}	22.82 mm	j_p	0.200 mm
h_0	$1.25 \cdot m_0$	r_{a2}	17.18 mm	j_{r1}	0.700 mm
a'	33.40 mm	x_1	+0.08	j_{r2}	0.759 mm
b	7.50 mm	x_2	+0.34	ε	1.229
z_1	12	k_1	-0.05	C	6.503 $cm^3/2\pi$

Thanks to this constructive solution, obtained through the interactive optimization of the parameters, it is possible to achieve an increase in displacement/revolution of 38.39% vs. units having a gear ratio of 1.
Compared to the units having a gear ratio other than one 1 (z_1 = 12 and z_2 = 8), but without interactive optimization of the parameters, we can see a further increase of: (6.503 - 5.604) / 5.604 = 16.04%; this

[1] m_0 = 3.25 mm ; α_0 = 20° ; $h_0 = 1.25 \cdot m_0$; a' = 31.80 mm ; b = 7.50 mm ; $z_1 = z_2$ = 9 ; $r_{a1} = r_{a2}$ = 18.97 mm $x_1 = x_2$ = +0.40 ; $k_1 = k_2$ = +0.06 ; j_p = 0.49 mm ; $j_{r1} = j_{r2}$ = 0.96 mm ; ε = 1.06 ; C = 4.699 $cm^3/2\pi$.

[2] The constructive and functional parameters of which fall within the permissible limits provided for correct sizing.

additional increase is exclusively due to the interactive variation of the three above-mentioned parameters.

Ratio $R = z_M / [(5/6)(2/sin^2 a_0)]$, where $z_M = (z_1+z_2)/2 + (_{x1}+x_2)/sin^2 a_0$, is equal to 1.021: a cut interference within what is considered as the permissible limit is present.

Needless to say, the wider the parameter percentage range and the greater the increase in displacement/revolution; vice versa, the same increase will be less the narrower the range, or, by interactively modifying only two of the parameters (in other words, by keeping either the operating center distance, pressure angle, or modulus fixed).

5. Influence on the sizing of j_p and j_r

Similarly to the aforementioned, a comparison study was conducted on real constructive solutions according to variants j_p and j_r (and to the abovesaid parameters); such comparison has shown that the top clearance j_r and the backlash at pitch diameter j_p also have an influence on displacement/revolution.

With regards to j_p, an increment of the latter would cause a significant increase in the level of interference, and only a minor increase in displacement/revolution.

With respect to the case under examination, by assigning the value of 0.49 mm to j_p – the same as that of the equal gear reference unit – instead of a value of 0.2 mm, a maximum value of C = 6.524 $cm^3/2\pi s$ (for: a' = 33.30 mm, α_0 = 22°, m_0 = 3.20 mm) is obtained.

This value is slightly greater than the one (C = 6.503 $cm^3/2\pi$) obtained by setting j_p = 0.2 mm; therefore, an increase in j_p is not recommended.

Far more relevant results, on the other hand, are those obtained by reducing the top clearance j_r, which has no negative influence on the interference but, at the same time, it allows the displacement/revolution to increase significantly.

As for the case under examination, by assigning the value of 0.300 mm to j_r (which means a value of 0.759 mm for j_{r2}) the displacement/revolution value is subject to a further increase equal to 6.67%: as a result, we get a total increase of 47.63% compared to the reference unit which has a gear ratio of 1.

The weight and dimensions of an optimized gear unit and those of a reference unit are practically the same.

Table 2 below shows the values of the parameters characterizing the optimized toothing as according to the criterion set out in this study.

Table 2. Gear unit obtained through the interactive optimization of parameters m_0, a_0, a', j_r

m_0	3.20 mm	z_2	8	k_2	-0.03
α_0	21°	r_{a1}	23.22 mm	j_p	0.200 mm
h_0	$1.25 \cdot m_0$	r_{a2}	17.18 mm	j_{r1}	0.300 mm
a'	33.40 mm	x_1	+0.08	j_{r2}	0.759 mm
b	7.50 mm	x_2	+0.34	ε	1.297
z_1	12	k_1	-0.18	C	6.937 $cm^3/2\pi$

6. Conclusions

The interactive optimization of the principal parameters characterizing a gear pump makes it possible to achieve significant increases in the displacement/revolution: as much as approximately 47 percent vs. non-optimized units.

The abovesaid comparison between optimized and non-optimized gear units refers to units of equal dimensions and weight.

By adopting such interactive parameter sizing criterion it is possible, on the other hand, to obtain a hydrostatic unit (gear pump) which, on equal displacement per revolution, has far smaller dimensions and weight versus the traditional one with a gear ratio of 1; in this way, for instance, by maintaining the operating center distance unchanged, we can obtain the same displacement per revolution

(proportional to the gears' axial length) with a significantly shorter toothed band.
The abovesaid results can be very useful both to the manufacturer (reduced production costs) and to the user (reduced weight and dimensions).

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