SCALING-LAWS BASED HYDRAULIC PUMPS PARAMETER ESTIMATION

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Lucrarea prezintă un exemplu de utilizare a legilor de similitudine în domeniul pompelor hidraulice volumice. Legile de scalare au fost obtinute pe baza informatiilor furnizate de producători reputati prin cataloage oficiale, referitoare la condițiile impuse pentru dimensionarea componentelor. Legile de scalare sunt utilizate pentru a transpune dimensiunile unui model la dimensiunile unui sistem real şi oferă setul de parametri necesari pentru proiectarea acestuia.

The paper presents an example of using the simple scaling laws method for hydraulic pumps parameter estimation. Scaling laws are derived from the basic equations of a certain component and validated using commercial datasheets. The scaling laws are used to adjust the dimensions of a model and provide the parameters needed for preliminary systems design.

Keywords: Scaling laws, preliminary design, hydraulic pumps.

1. Introduction

The scaling laws can be used in different domains as micro systems, mechanics, hydraulics and fluid mechanics, to compare different actuator technologies, to adapt the dimensions of a mock-up in fluid dynamics, to size mechanic, hydraulic or electric systems, to develop and rationalize product families or to evaluate costs. The use of scaling laws, also called "similarity laws" or "allometric" models, has the advantage of requiring only one reference component for a complete estimation of a whole product category.

A homothetic scaling of all the geometrical dimensions can lead to a single-ratio linkage to a representative reference component. Models will only be developed for components with a geometrical similitude.

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In some cases it is not possible to obtain a simple set of equations linking the desired parameters of a given problem. In this case, a dimensional analysis can lead to a better estimation of the scaling laws.

2. Scaling Laws

The current technical developments in aviation aim to make the aircrafts more competitive, greener and safer. The more electric aircraft (MEA) offers interesting perspectives in terms of performance, maintenance, integration, reconfiguration, ease of operation and management of power. This is often achieved employing to scaling laws, in order to take advantage of their capability to reflect the physical constraints driving the electromechanical components sizing. The established scaling laws provide the designer with parameters needed for holistic system integration.

From the overall requirements, the preliminary design task should allow synthesizing, assessing and comparing candidate solutions before taking decisions and going into the detailed design. These requirements are mainly composed of functional requirements for different operation modes, which become inputs of the architecting task that must define which types of components are involved and how they are organized, while following performance requirements and design constraints, as inputs for the multi-objective sizing of the components [1].

The system-level design steps require model linking directly primary characteristics, which define functionally the component to its secondary characteristics, which can be seen as the features of imperfections.

Generally at component level, the models link the physical dimensions and characteristics of materials used to the primary and secondary characteristics.

3. Objectives and Implementation

The main goal of the paper is to find the scaling laws for hydraulic axial piston pumps. The dimensions used are taken from REXROTH and PARKER datasheets. From REXROTH we have chosen A4VSO and A7VO series and from PARKER the PV series. For both series, the type of the pump is a swash-plate pump. Nominal pressure is 350 bar, rated speed is 1800 rpm for REXROTH and 2500 for PARKER. The hydraulic circuit is considered to be an open one.

Hydraulic displacement is an important parameter, so it has been chosen as a reference; it is the most commonly available variable in literature, representing the volume of liquid through a full rotation of the drive shaft under zero pressure difference between joints. It is noted with V_g or V and it is also named “geometric volume of work” [2]. Since it is a parameter common to all the volumetric pumps, we will try to define scaling laws that are based upon it.

After choosing the main parameter, we can also choose the data for both brands, from their respective datasheets. The data can be seen in the next part, logarithmic approach.

4. Logarithmic Approach

Using the scaling laws directly, we will presume that the accuracy of our calculation is good enough. By using another approach, we will strengthen the relationship between some commercial products and the theory of scaling laws.

The objective is that by using an inverse process, starting from the products that already exist in the market, we can derive a relationship that can be used to scale a newer component to a target system. Usually, the scaling laws are expressed by a rational power formula. We will prove that the value of the *power x* fits totally with scaling laws calculations [3].

In order to obtain the value of the power, we charted the main parameters, as given in the datasheets: mass, rotational speed, flow and inertia versus the chosen basic parameter: hydraulic displacement.

First, we selected relevant data for our pump categories. Once we have this information, we move to the second step, consisting of plotting the data on a logarithmic graph. This way, by interpolating the data with a first order curve, we can find the slope which represents a power function expressing the dependency between parameters.

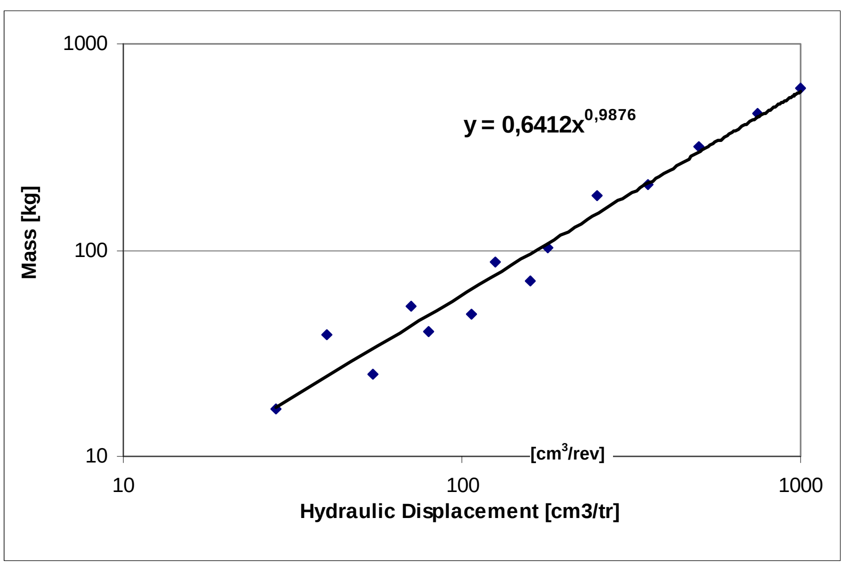

Fig. 1. Hydraulic displacement as a function of mass for REXROTH axial piston pumps

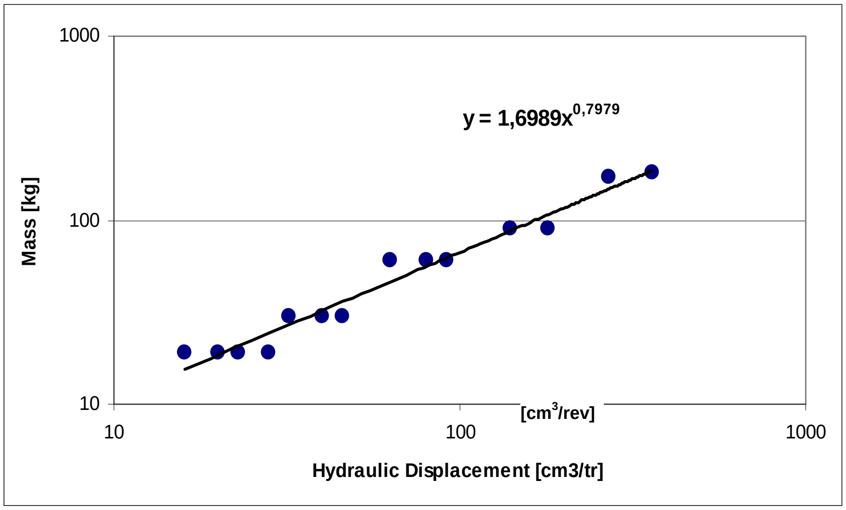

Fig. 2. Hydraulic displacement as a function of mass for PARKER pumps

The same principle is applied to the other parameters, so, after going through all the components in a series, we will have the power functionthat corresponds to a possible relationship between each parameter and the hydraulic displacement. After studying each of the series, a global approach to the same process is also done in order to have different point of view of the products with such a theory.

In the next table are presented the results of the logarithmic approach, the power obtained from graphs.

Table 1

Results for logarithmic approach

REXROTH

Variables	Power
Rotational speed [rev/min]	-0.2933
Flow [L/min]	0.7063
Moment of inertia [kg m^2]	1.7284
Mass [kg]	0.9876

PARKER

Variables	Power
Rotational speed [rev/min]	-0.1768
Flow [L/min]	1.0497
Moment of inertia [kg m^2]	1.4674
Mass [kg]	0.7979

5. Analytical Approach: Scaling Laws

In this part we will go roughly through the physical and mathematical calculation in order to find the equations and the relationships among the variables [1], [2], [4].

The main parameters are mass, inertia, rotational speed, flow and hydraulic displacement. The scaling laws that we have obtained are synthesized in the next table.

Table 2

Scaling laws

	VARIABLES	SCALING LAWS
Definition parameter	Hydraulic displacement [m^3/rev]	V_g^*
Integration parameter	Mass [kg]	$M^* = V_g{}^*$
Simulation parameter	Moment of Inertia [kg m^2]	$J^* = V_g{}^{*5/3}$
Operational limit parameters	Rotational Speed [rpm]	$\omega^* = V_g{}^{*-1/3}$
	Flow [L/min]	$Q^* = V_g{}^{*2/3}$

Now that we have the scaling laws, we can apply them to existing data and see what results we will obtain.

Table 3

Power function from analytical approach

Type of approach	Rotational speed [rev/min]	Flow [L/min]	Moment of Inertia [kg m^2]	Mass [kg]
Analytical approach	-1/3	2/3	5/3	1

If we make a comparison between the power obtained from the logarithmic approach and the power function obtained from the analytical approach we have:

Table 4

Comparison between power function from logarithmic approach and from analytical one

Type of approach	Series	Rotational speed [rev/min]	Flow [L/min]	Moment of Inertia [kg m^2]	Mass [kg]
Logarithmic approach	**REXROTH**	-0.2933	0.7063	1.7284	0.9876
	PARKER	-	1.0497	1.4674	0.7979
Analytical approach		-0.3333	0.6666	1.6666	1

In order to apply the scaling laws we need first to find the formulas between variables and to find the best reference. The formulas have been presented above and the references are presented in the next tables.

Table 5

The reference used for calculations for REXROTH series

	Size	Hydraulic displacement [cm^3/rev]	Rotational speed [rpm]	Flow [L/min]	Moment of Inertia [kg m^2]	Mass [kg]
Reference	180	180	1800	324	0.055	102

Table 6

The reference used for calculations for PARKER series

	Frame Size	Hydraulic displacement [cm^3/rev]	Rotational speed [rpm]	Flow [L/min]	Moment of Inertia [kg m^2]	Mass [kg]
Reference	5	360	1750	540	0.103	180

The predictive significance of the scaling laws can be observed in the next figures, which plots the data from catalogue versus the estimated data [5].

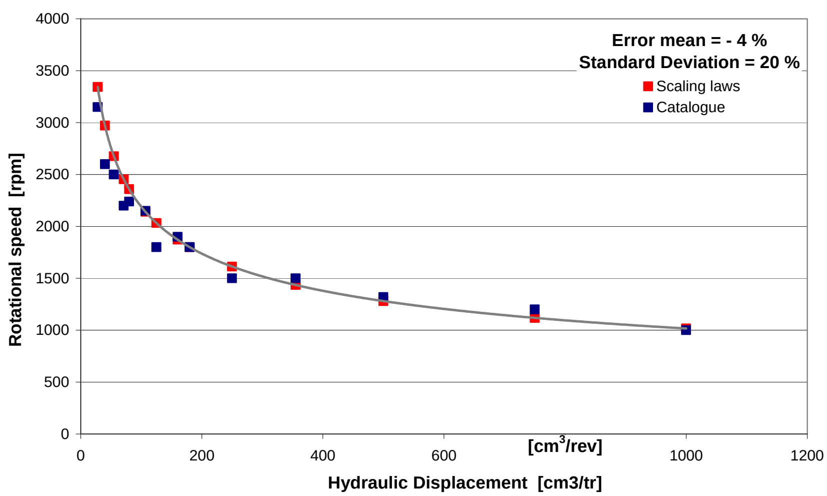

Fig. 3. Rotational speed function of hydraulic displacement for REXROTH pumps

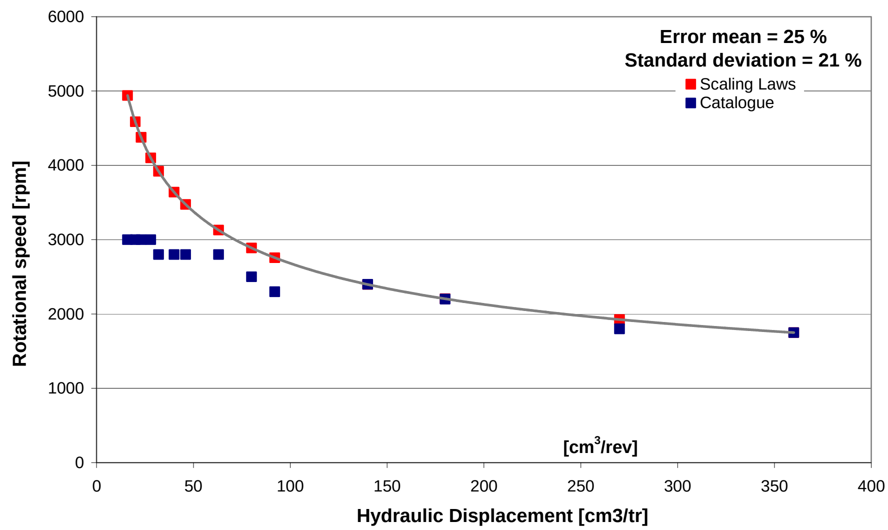

Fig. 4. Rotational speed as a function of hydraulic displacement for PARKER pumps

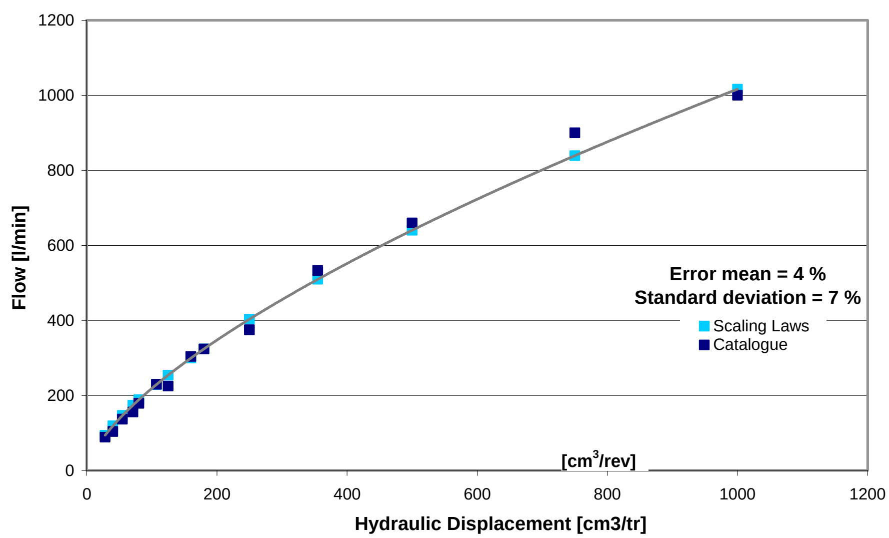

Fig. 5. Flow as a function of hydraulic displacement for REXROTH pumps

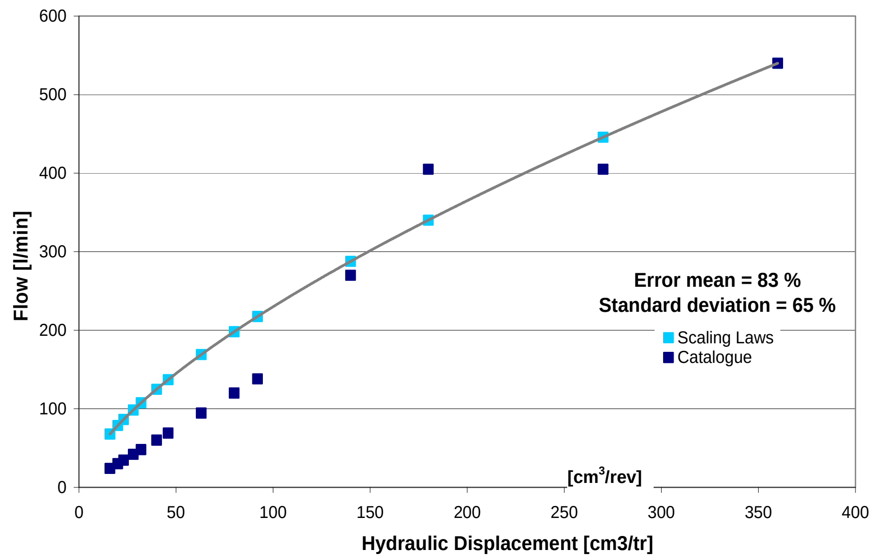

Fig. 6. Flow as a function of hydraulic displacement for PARKER pumps

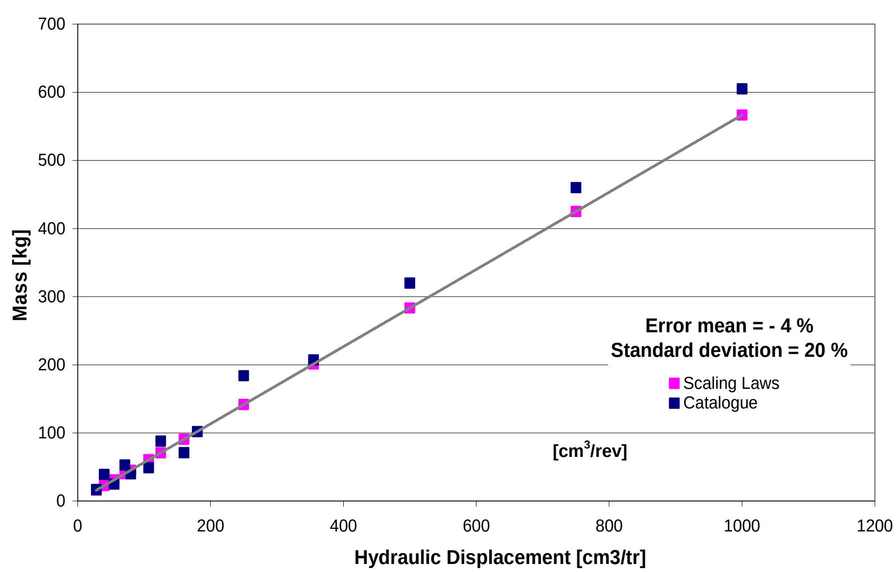

Fig. 7. Mass as a function of hydraulic displacement for REXROTH pumps

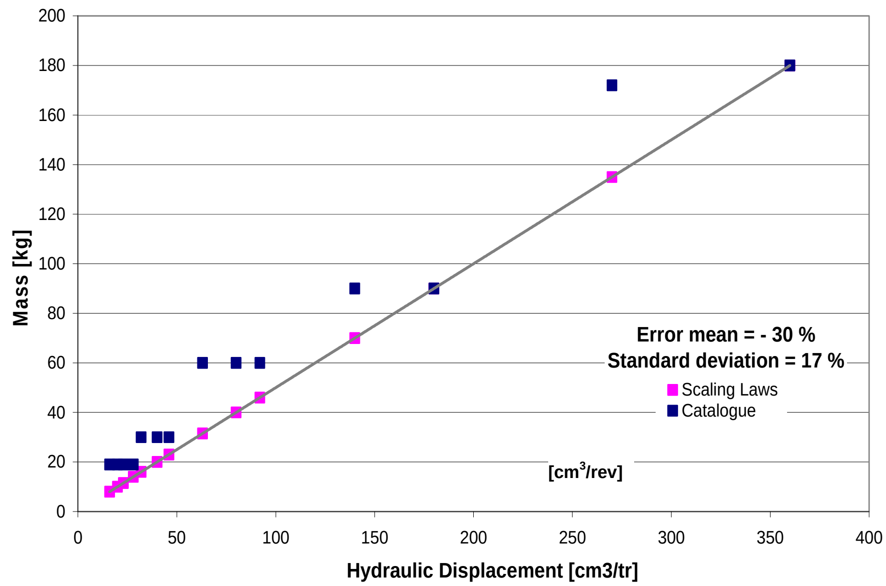

Fig. 8. Mass an a function of hydraulic displacement for PARKER pumps

Comparing the results from Parker with the results form Rexroth, it can be observed the Rexroth seems to rely more on geometric similarity. While the use of scaling laws in final stages of design is impossible, the error being too high, for preliminary design it is a time-saving alternative to classical simulation. A larger database could improve the results, which were derived based on a limited set of components.

6. Conclusions

The use of scaling laws offers significant potential for reducing development costs and improves design quality. It allows studying and testing of a larger number of architectural concepts and decisions before constructing a physical prototype. Despite the numerous papers on virtual prototyping, there is a lack of appropriate simulation models for preliminary design. Scaling-laws based simulation models could offer a viable alternative to classic models, especially in the preliminary design stage.

The derivation of these laws based on physical phenomena, which dominates the design of components, is a difficult task. They require a deep knowledge of components and their technologies, while taking into account the constraints and limitations for sizing their area of operation.

Acknowledgement

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R E F E R E N C E S

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