A PRAGMATIC APPROACH ON RATIONALIZATION AND AUTOMATIC SELECTION OF WATER PUMP IMPELLERS: A CRUCIAL ASPECT OF WATER RESOURCES AND ENVIRONMENTAL ENGINEERING

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Abstract

Discussed in this work is the outlined mathematical modeling procedure that can help to automate the often-difficult design and selection of the optimum water pump impeller for a given task. Also discussed are, ways and how to automate the selection process; how to approximate the surface by a mathematical model-through the group of How rate — speed - pressure points modeled by a function P = f (Q,n). The methodology was based on the Multilevel B - Spline Approximation Algorithm (MBA) which made it very easy to select automatically, the most appropriate water pump impeller. However, the difficulties involved in the process of designing a water pump impeller suggests the re-use of knowledge acquired during the past projects, meaning that, for selection criteria, it is necessary (o use the characteristic curves of previously designed impellers '- by way of mathematical modeling.

Introduction

The impeller is the heart of a water pump and the main origin of its behavioural efficiency. An impeller that is badly designed in relation to a specific work point produces losses at the inlet, along the blade aricTalso separation losses.

Many mono-dimensional models allow estimation of these losses; the best - known models are those of Japikse (1984); Neumann (1991); Tuzson (1993); Stepanoff (1993); Japikse, Marsher and Furst (1997) and Tuzson (2000);) and There are also many other studies, building more or less on these previous models, that suggest some procedure lo design water pumps (Veres, 1994; Moore & Atkinson 1997; Oshima & child 1999; and Zoz, Thclen, Alcenius and Wiseman 2001).

The main limitation of these models is their approximated behaviour: an optimization process cannot start from these models. The answer to this problem is given by the Computational Fluid Dynamics (CFD) simulation technique. This technique allows calculation of the flux distribution by the solution of the Navier stokes partial differential equations.

Optimization still remains a critical process and it is difficult to automate it. The designer usually develops a first attempt and tests it. According to the result, the geometry is modified to improve the flux distribution, and re-tried. This iterative process is repeated until the designer thinks that the i-th step gives a good result (in relation to his own experience).

Some studies according to Deguchi, Fujita and Nomato (2000), also propose analysis of the contribution of each geometrical parameter based on a .multivariate analysis (Principal Component Analysis). Here the authors repeat different Computational Fluid Dynamics (CFD) simulations with different geometrical parameters and study the influence of each factor. These studies help the designer to analyse only a few geometrical parameters, reducing the size of the manual optimization, and therefore, the time for the optimization - the number of iterations.

This process has been much improved in recent years, kudos to the development of multi-objective optimization software. Software based on the use of genetic algorithm parallel hill Climbing, parallel architectures and Pareto frontiers has according to Bze, Obiegbu and Jude-eze (2005); Spicer, (1998); Igbe (1995), and Igbe (1999), provided the possibility to automatically run generic computational Fluid Dynamics (CFD) software..:but in general, a generic design tool. The optimizer, interacting with the CFD software, progressively modifies the geometry of the impeller until the optimum geometry is reached (Spicer, 1998; Spicer, Cook, Poloni and Sen, 1998).

In recent years, some new optimization processes have been developed based on a different philosophy; the main exponent of this development are those of Zangeneh (1997); Yiu and Zangeneh (1998); and Zangeneh, Goto and Harada (1999). The approach is different, or, put in a better way, is, "inverse": a specific blade loading is assigned and the geometry that produces that blade loading is calculated using 3D inverse design methods. An optimizer can modify some parameters that define blade loading, so that the optimization is an easier task than previously.

Manual or automatic optimization processes involve many difficulties. This observation justifies the necessity to record new knowledge resulting from the optimization process. This problem becomes particularly important if this optimization process is a daily task, as for water pump builders. The majority of well-designed impellers suggest the re-usability of the impellers. So the problem is; "how to proceed in this operation?"

The main idea is to use the experimental curves of the water pumps. These curves represent the pressure-flow rate relationship at a specific speed-figure 2b shows the flow rate relationship. The group of such curves is a surface space. This surface has to be compared with the specific flow rate, head and speed required-by the customer.

Mathematical Approximation of the Surface

If we want to automate the selection process, it is necessary to approximate the surface by a mathematical model. The group of flow rate - speed - pressure points has to be modeled by a function P=f(Q,n).

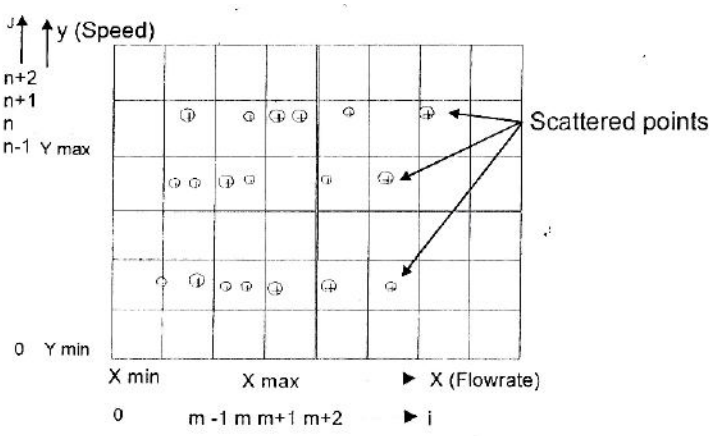
There are many mathematical ways to approximate the surface-scattered data points; neural networks according to Haykin (1998), nurbs (non-uniform rational B -splines) and B- spline approximations according to Piegi and Tiller (1996), are only some examples. The modification of [• r last-mentioned method has been chosen because, the algorithm is very fast.

Methodology

The methodology is based on the Multilevel B - Spline Approximation (MBA) Algorithm, pnposed by Lee, Wolberg and Shin (1997); it consists of the surface approximation by a uniform cubic B- Spline function defined by its control lattice O (See figure I below). Also, the mathematical details are given below.

Figure I:

Lattice Overlaid to Scattered Data Points



Methodology of the Approximation

The MBA algorithm methodology proposed here consists of the surface approximation by a uniform cubic B-spline function defined by its control lattice O overlaid on its definition domain

$$\Omega = \{(x,y)/\ xmin \leq x \leq x_{max}',\ y_{min} \leq y \leq y_{max}\}$$

$$B_1(t) = \frac{3t^3 - 6t^2 + 4}{6}$$

jith control point on lattice Φ.

n is defined as:

$$B_2(t) = \frac{-3t^3 + 3t^2 + 3t + 1}{6}$$

$$B3(t) = \frac{t^3}{6}$$

$(i+k)(j+l)$

Where: $0 \leq t < 1$

$$\Delta x = \frac{x_{max} - x_{min}}{m-1}$$

(m is the dimension of the lattice in the x direction; similarly n is the dimension of the lattice in the y direction)

$$i = \text{trunk} \frac{x - x_{min}}{\Delta x}$$

$$s = \frac{x - x_{min} - i\Delta x}{\Delta x}$$

In a similar way we can define j and t as functions of y.

B_k and B_l are uniform cubic B-spline basis functions defined as:

$$B_0(t) = \frac{(1-t)^3}{6}$$

Control points <Dy have to be chosen in such a way in the assigned points x_c> y_c that the next condition (where z_c is the pressure value) is satisfied:

$$Zc = \sum_{k=0}^{3} \sum_{1=0}^{3} w_{kl}\, \Phi_{kl}\ (w_{kl} = B_k(s)\, B_l(t))$$

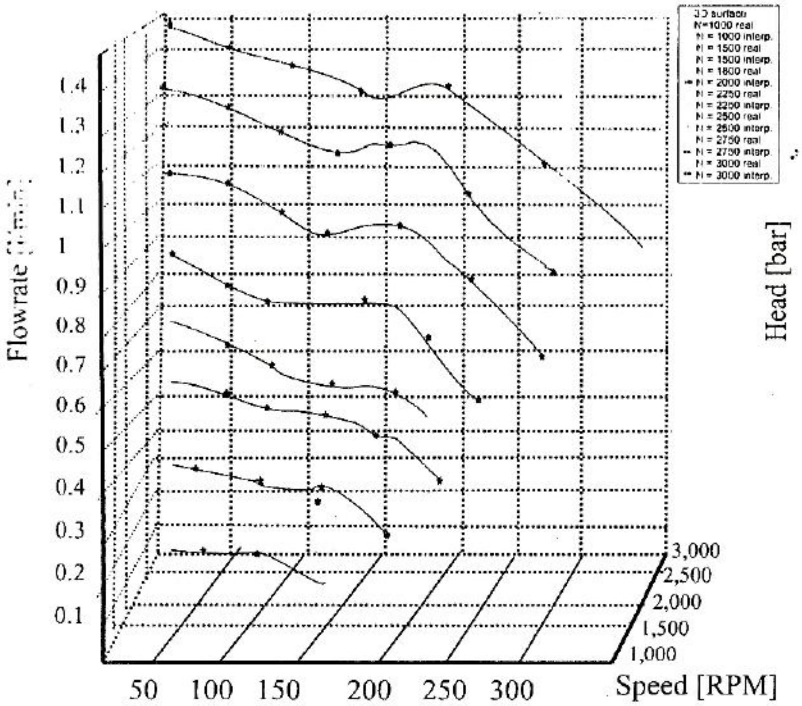
A possible choice consists in the minimization of the quadratic mean error. This method brings us to the solution:

$$\Phi_{kl} = \frac{w_{kl}\, Z_c}{\sum_{a=0}^{3} \sum_{b=0}^{3} w^2 ab}$$

The second behaviour of the algorithm is that it is multilevel. Given the lattice, it is possible to proceed with the calculation of the approximation function. This approximation function in the assigned points X_c, y_c (flow rate and speed) returns an error. So we use a second, finer lattice (second level) that has the scope to approximate the previous error, the difference between the desired output and the estimated value obtained by the function defined previously. The function is modeled by two approximations. With the increment of the number of levels, the marginal error is reduced, but in the siimc way the complexity of the approximation function is improved. The software implementation of the previous method gives the result as shown in figure 2 below.

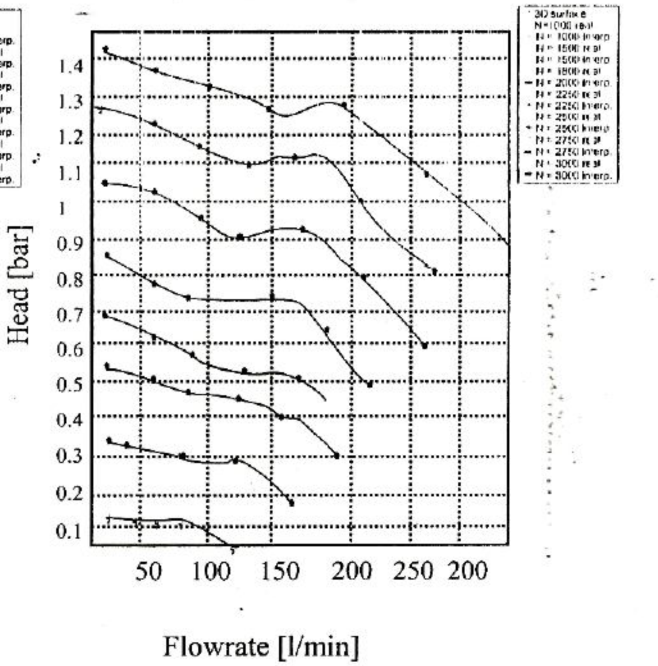
Characteristic Head - Flow rate Speed Surface of a Water Pump

(Fig. 2.a)



PA6.8109.0 Curves

(Fig. 2.b)

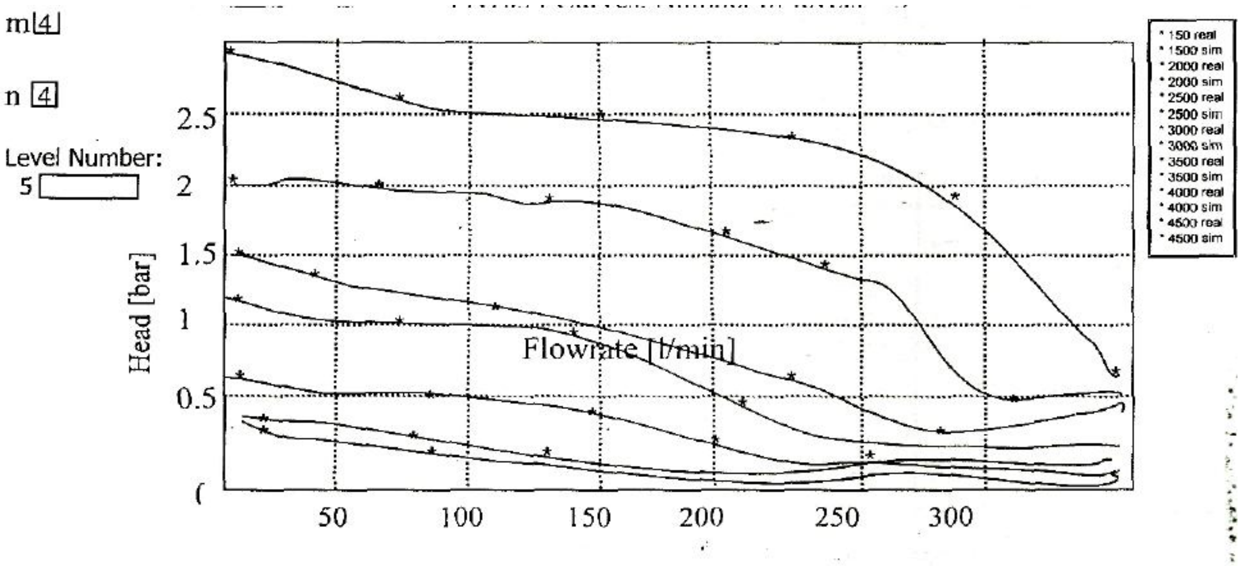


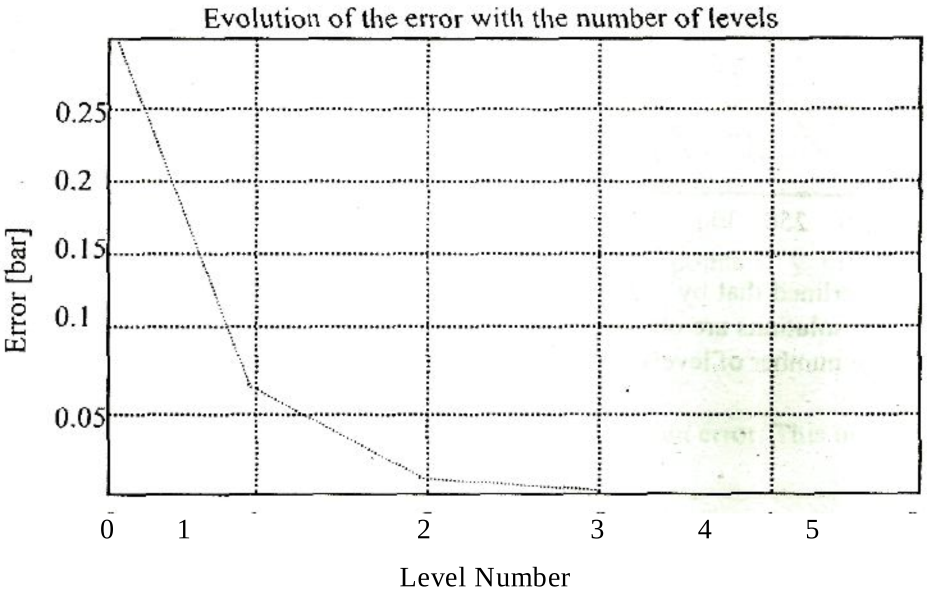
PA6.8I09.0 Curves

It must be underlined that by changing the dimensions of the starting lattice (m x n) and the level number, different solutions are obtained. In particular, figure 3 shows the evolution of the mean quadratic error with the number of levels and the final curves obtained by the algorithm.

Figure 3: Error Evolution with Level Number (Below Fig. 3.b) and Final Characteristics Curves (Above Fig. 3.a)

' PA1054 Curves. Number of levels = 5





This algorithm is particularly efficient because it is very quick to supply the desired output: less than 1 second is necessary to model entirely the surface using approximately 40 scattered points, with m — n = 3 and with six levels. The second advantage of the approach is the very low approximation error. To give an idea, a mean error in the assigned points, in terms of pressure, is less than 10"^{5} bar.

Selection

After the surface is modeled, it is very easy to select automatically, the most appropriate water pump. The user introduces the required work point; in particular, flow rate and speed are the inputs for the i-th pump mathematically modeled by the Multilevel B- Spline Approximation (MBA). The output (pressure) is calculated by the mathematical function and then compared with the desired pressure; if the difference between the two values is less than a specific threshold the pump is chosen.

In the opposite case, the selection process is refined; the vicinity of the specified speed and flow rate is examined,' and the software automatically verifies if the pressure stays inside some specific limits. The chosen process finally produces a tangible result in the form of a list of possible suitable impellers. See figure 4 below;

The list of Impellers and (heir Hydraulic Behaviours Selected by the Software

	Q[l/min	P[bar]	N [RPM]
REQUIRED	67.0	0-900	2500
PA 6.7851.0	67.0	0.973	2500
PA6.8109.0	67 0	0.973	2500

Conclusion and Recommendations

The difficulties involved in the process of designing a water pump impeller Suggests the reuse of knowledge acquired during past projects. This means that it is necessary to use the characteristic curves of previously designed impellers; so a mathematical modeling is necessary to automate the selection process, the designer can either choose the impeller exactly as suggested (and his work is finished or starts to modify and optimize, manually or automatically the geometry suggested by the selection software. This optimization process will be faster because the starting geometry will be very close to the desired geometry, so only a few interactions will be necessary.

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