Modification of Centrifugal Pump Performance Through Impeller Trimming

By

Eng. Medhat William Abd El Malak Mansour

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the Requirements for the Degree of

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In
MECHANICAL POWER ENGINEERING

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Title of Theses: Modification of Centrifugal Pump Performance Through Impeller Trimming

Key Words: Computational Fluid Dynamic, Best Efficiency Point, performance, Affinity Law, Impeller Trimming

Summary: For reasons of operating costs, the pump performance curve is adjusted to meet the pumping system. One of these modifications is impeller trimming. Impeller trimming is decreasing the impeller diameter in order to modify the best efficiency point (BEP) on the performance curve of the pump to meet the pumping system for saving energy. The centrifugal pumps was tested at impeller standard diameter and with trimming 2%, 5% and this pump was modeled using (CF turbo) program and predict to performance of the pump using the Computational Fluid Dynamics (CFD) and Verification the numerical results with the experimental results. The results were encouraging to apply the same method on the large centrifugal pump, which it was tested at standard impeller diameter and this large centrifugal pump has been simulated at impeller trimming 2%, 5% and 7%.

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The test was on the centrifugal pump working in "Amiri station" in “Holding Company for Drinking Water and Sanitation”

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Nomenclature

Symbol	Quantity
A	Axial distance from the leading edge (m)
A	Area, cross section (m^2)
A_{3q}	Volute inlet throat area $(A_{2q} = a_3 \times b_3)$ (m^2)
b_2	Impeller outlet width (m)
C	Absolute velocity (m/s)
C_m	Meridional velocity component of the liquid (m/s)
C_u	Velocity component of the liquid in the direction of U (m/s)
CE	Equivalent velocity component of the liquid in the direction of U (m/s)
d_2	Full impeller diameter (m)
d_n	Hub diameter (m)
e	Blade thickness (m)
F	Force (N)
g	Acceleration due to gravity (m/s^2)
H_{tot}	Total head (m)
k	Turbulence Kinetic Energy
L	Blade Length (m)
T	Torque $(N.m)$
m	Mass (kg)
$m^{\bullet}$	Mass flow rate (kg/s)
$NPSH_R$	Net positive suction head required
n	Rotational speed (rpm)
n_q	Specific speed
p	Power (W)
p	Static pressure (pa)
Q	Flow rate (m^3/s)
QI	Flow rate between two consecutive blades (m^3/s)
Q_u	Volume of liquid displaced per unit of time by a moving blade (m^3/s)
q^*	Flow rate referred to flow rate at best efficiency point:
R,r	Radius (m)
SG	Specific gravity; $SG \equiv \rho / \rho_{Ref}$ with $\rho_{\mathrm{Ref}} = 1000$ kg/m ^{3}
t	Time (s)
U	Peripheral velocity of a blade (m/s)
u	Circumferential velocity (m/s)
V	Volume (m^3)
W	Relative velocity (m/s)
W	Power transmitted by the blades to the liquid (W)

y^+	Dimensionless distance from the wall
Z	Number of blades

Greek Letters

α	Angle between direction of circumferential and absolute velocity
β	Blade angle
ε_{sp}	Wrap angle of the inner volute
ε	Dissipation Rate
η	Overall efficiency (at coupling)
η_V	Volumetric efficiency
η_h	Hydraulic efficiency
λ	Power coefficient
ρ	Density $\left(kg/m^3\right)$
φ	Flow coefficient
ψ	Head coefficient

Subscripts

opt	Operation at maximum (best) efficiency (BEP)
u	Circumferential components
n	Refers to the n^{th} element of a blade

Abbreviations

BEP	Best Efficiency Point
Chap.	Chapter
Sec	Section
CFD	Computational Fluid Dynamics

Abstract

For reasons of operating costs, the pump performance curve is adjusted to meet the pumping system. One of these modifications is impeller trimming. Impeller trimming is decreasing the impeller diameter in order to modify the best efficiency point (BEP) on the performance curve of the pump to meet the pumping system for saving energy. So it was necessary to study the impeller trimming and its effect on the pump performance, and to provide a method for predicting the pump performance after the trimming process using simulation through the Computational Fluid Dynamics (CFD).

In this thesis, the centrifugal pump was tested at standard impeller diameter, as well as with trimming 2%, and 5%. This pump was modeled using (CF Turbo) program in order to predict the performance of the pump using the Computational Fluid Dynamics (CFD) and Verification of the numerical results was done using the experimental results.

The results were encouraging to apply the same method on a large centrifugal pump, which was tested at standard impeller diameter. Moreover, in this thesis, the performance of large centrifugal pump has been simulated at impeller trimming of 2%, 5% and 7% respectively. Mesh volumes were used in the two pumps, where, optimization of mesh size was selected for both solution accuracy minimum time and allocated memory.

Through this research, the same steps can be applied for other pumps and to predict their performance. Also, it can apply other modifications on the impeller using the same method.

Chapter 1: Introduction

1.1. General

Centrifugal pumps as important part of any pumped plants are consumers of great energy. Due to high capacities of pumped plants, efficient operation of all their components, including centrifugal pumps is very important. It is often found that centrifugal pumps do not operate in their best points for various reasons, because of approximation trying to provide gradual increases in pipe surface roughness and flow resistance over time, or expect future plant capacity expansions. Furthermore, the pumping system requirements may not be clearly defined during the design phase. So, the pumps may be having different operating points than their design points. This can cause cavitation and energy waste as the flow rate must be regulated with by passes or throttle control. For manufacturing standardization purposes, pump casings and shafts are designed to accommodate impellers in a range of sizes. Many pump manufacturers provide pump performance curves that indicate how various models will perform with different impeller diameters or trims [1].

For these reasons, must be modify the design point of the pump to meet the operating point of the pumped system. This modification can be done by using three methods such as variable-speed control, throttle valve and impeller trimming; the best method is impeller trimming [2].

Impeller trimming is the technique where the impeller diameter of a centrifugal pump is machined to a smaller one, the purpose of this is to modify the characteristics of centrifugal pump with a constant speed so as to meet the demand on the specified flow rate and head in pumping systems. The impeller trimming advantages are reducing operation and maintenance costs including less liquid energy wasted, relief of noise, vibration and wear in pumping system pipeline, valves and pipeline supports [3]. So, the oversized and throttled pumps that produce excess pressure are candidates for impeller replacement or trimming to save energy and reduce costs.

The trimming should not be more than 75% of maximum impeller diameter, because excessive trimming; due to a mismatched impeller and casing, increases internal flow recirculation; causes head loss, and lowers pumping efficiency [4].

1.2. Purpose of Impeller Trimming

A given pump size is employed to cover a certain performance range. For example, Figure (1-1) shows a range chart for pumps operating at $(n = 2950\ rpm)$. It contains (27) pump sizes which are described by the nominal diameter of the discharge nozzle (first number) and the nominal impeller outer diameter (second number). Sizes arranged in the chart in a nearly vertical column deliver similar volumetric flow rates and therefore have the same nominal discharge nozzle diameter. Sizes arranged in horizontal rows have identical impeller diameters and produce a similar head. The specific speeds of the individual sizes increase from top down and from left to right Pumps with the same specific speed are found, in a double-logarithmic graph, on inclined straight lines. It allows a rapid selection of possible pumps which can be considered for a specific application.

Theoretically, the pump of all sizes with the same specific speeds (n_q) are geometrically similar, but actually the different sizes of the same (n_q) often deviate in some design details from geometric similarity and the available demands for a pump with a low speed may be uneconomical. So, the impeller trimming is a good method for achieving economic goals in the operating without loss of energy by throttling and avoiding the rigid selection of the pump.

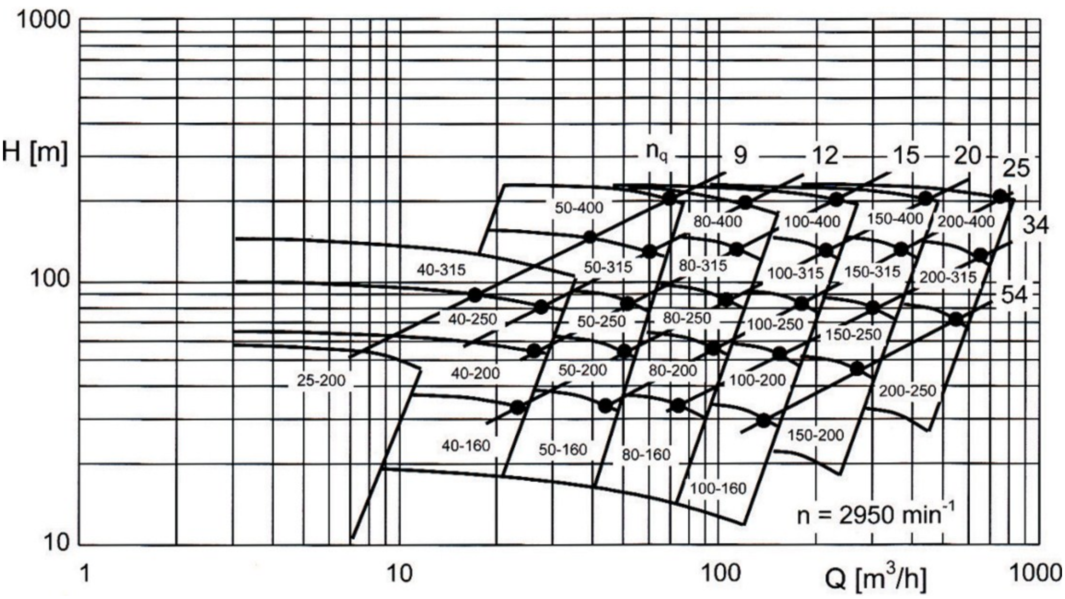

Figure (1-1) Range chart of process pumps, SULZER pumps [5]

Figure (1-2) shows how changing in characteristics of a pump size by changing impeller diameter at the constant efficiency (η), where, (d_2^*) is the diameter ratio $(d_2^* = d_{2,i}/d_2)$, $(d_{2,i}, d_2)$is the impeller diameter after and before trimming respectively, and (ψ, λ, φ) is the coefficients of head, power and flow, respectively. These coefficients decreased by impeller trimming of 5%, 10% and 15%. The impeller trimming allows adjusting pump performance to suit pumping system and more flexibility in pump selection.

Generally, it must be taken into consideration all parameters such as impeller diameter, specific speed(n_q), number of stages and standard speeds for covering the following:

- Complete coverage of the field
- Number of sizes required