JID: ADES [m5G;November 14, 2015;8:8]

Advances in Engineering Software 000 (2015) 1–8

Contents lists available at ScienceDirect

Advances in Engineering Software

journal homepage: www.elsevier.com/locate/advengsoft

Optimization of pump efficiencies with different pumps characteristics working in parallel mode

M. Koor [a], A. Vassiljev [b,*], T. Koppel [b]

[a] AS Tallinna Vesi, Tallinn, Estonia
[b] Tallinn University of Technology, Estonia

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Water distribution system
Energy
Pumps
Efficiency

ABSTRACT

This paper concentrates on an algorithm for the prediction of steady running variable speed pumps (VSPs) working in parallel to keep them running close to the best efficiency point (BEP) provided by the pump manufacturer. Special focus is on the pumps that have different efficiency and performance characteristics. The complex optimization task to maximize the total efficiency of the pump system and thereby minimize energy consumption was solved with the customized optimization software using the Levenberg–Marquardt algorithm (LMA). Three different theoretical scenarios were analyzed: with working pumps having identical, slightly and largely different characteristics. The transition curves are proposed on the basis of optimization that indicate water discharge and pressure head when an additional pump should be switched on to ensure the highest total efficiency of the pump system.

1. Introduction

This paper shows that energy consumed by a Water Distribution System (WDS) may be reduced by increasing the efficiency of the pumps. Improved efficiency of the pumping systems also contributes to the reduction of greenhouse gas emissions and reduction of environmental impact. The task is essential in WDSs with no elevated storage tanks where pressure in the system is regulated only by pumps. The WDS of Tallinn Water is an example of such a system [1].

First methods to solve complex WDS optimization tasks appeared along with the first digital computers already in the 1960s. Since then the development of different optimization algorithms has increased rapidly. For example, Coulbeck and Orr [2] used the dynamic programming (DP) technique to optimize the basic pump scheduling procedure and pump combination selection. Also, Zessler and Shamir [3] carried out optimization to find the optimal decisions for pumps and valves for a 24-hour period using the progressive optimality (PO) technique based on dynamic programming (DP). Ormsbee, et al. [4] focused on finding an optimal pump usage policy to minimize the pump operational cost in a water distribution system according to variable electricity rate schedules and system demand schedules. As a result, an optimal water level trajectory in the tank and pump operating policy was developed to achieve higher efficiency of a pump system. Yu, Powell and Sterling [5] used an algorithm based on nonlinear programming to determine optimal pump schedules. But the complexity of WDSs limits the use of conventional optimization methods such as linear and nonlinear programming. A need to optimize more than one objective or goal led to the development of more complex multi-objective stochastic optimization methods such as simulated annealing, evolutionary algorithms and neural network.

To achieve maximum efficiency of the pump system, optimization of pump work schedules and pump control settings has been a high priority research theme for many years. Pump's efficiency usually degrades during normal operation due to wear by as much as 10–25% before it is replaced. Efficiencies of 50 to 60% or lower are quite common in older pumping stations, as described in [6]. It is estimated in [7] that ca 75% of the pumping systems today are oversized. A pump is considered as generally oversized when operated at lower than 20% of its best efficiency point (BEP) [8], although it is normally considered acceptable if the duty point of the pump falls within 20% range of the BEP flow rate. At the same time, pumps can also become undersized due to the WDS increased. A pump operating beyond its BEP will also experience increased noise and vibration. Running a pump continuously at such extreme regime will reduce pump's life time considerably. In practical applications, operating a pump continuously at its BEP is uncommon, because pumping systems must adapt to the constantly changing flow rate and the system head. To achieve better results, different mathematical models and techniques are used in the simulation and optimization of pump stations [3,4,5,9,10]. Comprehensive and practical methods and tools were required to estimate and optimize the energy efficiency. Many best practice guides were prepared, for example in [6] to help

* Corresponding author. Tel.: +37258136243.
E-mail address: anatoli.vassiljev@ttu.ee (A. Vassiljev).

http://dx.doi.org/10.1016/j.advengsoft.2015.10.010
0965-9978/

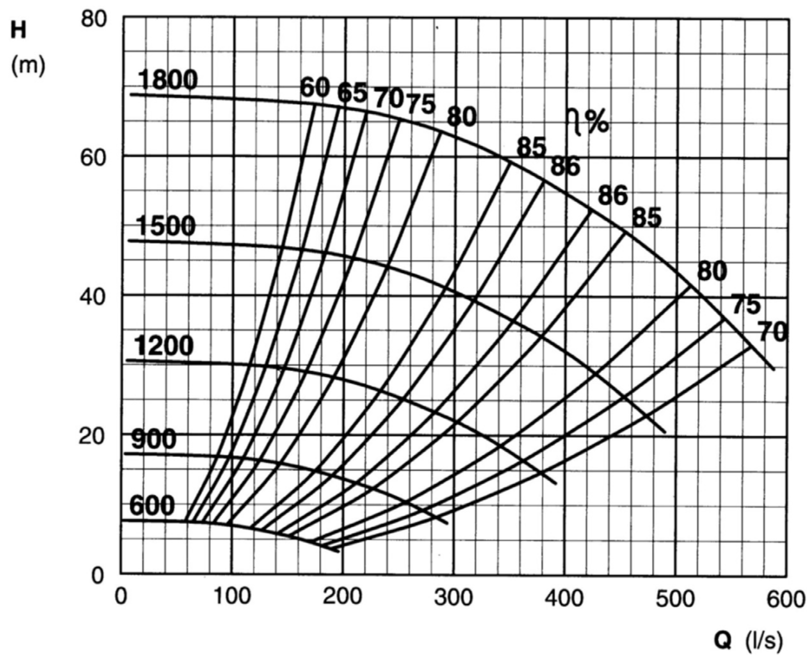

Fig. 1. Universal characteristics of the new pump.

Table 1
Water discharge at the highest combined efficiency calculated for a different number of pumps.

Number of pumps	Pump 1 flow (l/s)	Pump 2 flow (l/s)	Pump 3 flow (l/s)	Pump 4 flow (l/s)	Pump 5 flow (l/s)	Total flow, (l/s)	Total efficiency, (%)
3	366.67	366.67	366.67	–	–	1100	81.9
4	275	275	275	275	–	1100	86.7
5	220	220	220	220	220	1100	84.6

industries to start improving their pumping systems step by step. Describing the pumps working in the oil industry, Crease [11] states that identical pumps work with the highest efficiency (running in parallel) if they operate at the same conditions. Tianyi, et al. [12] also showed that pumps running in parallel and controlled by variable frequency drives are most efficient when all pumps work at the same speed. Both of these investigations were carried out for pumps working outside WDSs (in the oil industry and in air-conditioning systems). Analysis of pumps for a WDS is more complex, as a WDS usually contains elevated storage tanks and therefore joint action of pumps and elevated storage tanks must be analyzed. The task may be very complex. Some steps to solve the problem are proposed in [13], including simplification of the WDS model. Efficiency of a variable speed pump (VSP) working under both varied system demand and pump head was investigated in [14,15]. In this regard, the Tallinn WDS differs from other systems because it contains no elevated storage tanks and the analyses of pumps covered in [11,12,14,15] may be useful in this case. Two common issues to be overcome in the operation are unnecessary demands in the network and oversized pumps. Focus of this paper is on the creation of a control algorithm that enables maximization of the total efficiency of a pump group and recommends when to start/stop extra pumps based on the required flow. Pump (Q, H) performance and efficiency characteristics are usually provided by manufacturers. The performance of a single new pump is typically described by a graph plotting the pressure head generated by the pump against the needed flow rate. The performance curves for a typical centrifugal pump are shown in Fig. 1. A single pump is often unable to consistently operate close to its BEP because of a wide variation in the WDS requirements. Therefore, pump batteries consisting of several smaller pumps running in parallel are often used to serve the pumping requirements of a WDS, particularly those with large differences between the flow rate required during the normal system operation and that required during the maximum system flow conditions. Koor, et al. [16] carried out practical research to find an optimal number of working pumps for identical pumps working in parallel. Optimal pump count areas with pump switching points were calculated based on the required flow and the pump head.

The aim of this paper is to analyze further possibilities to optimize the work of a pump group that consists from non-identical pumps. The paper is based on the previous research of Koor, et al. [1], but significant improvements and extensions have been made. The equation for the calculation of the total efficiency of the pump group was changed, another method of calculation of the efficiency at different pump heads was proposed. To solve the task, the optimization software developed by Argonne National Laboratory (University of Chicago) was used. Minpack package, which uses the LMA algorithm, has been rewritten from FORTRAN into Visual Basic and into Visual C++. Software was slightly modified to enable its usage with the current optimization task. The result was tested on the basis of three scenarios - pumps are identical, characteristics of pumps are slightly different and differences between the characteristics of pumps are quite large.

2. Analysis

2.1. Description of the tasks

Let us assume that the number of pumps in the pumping station is n; all the pumps can be switched on and off and their revolutions per minute (rpm) are adjustable. In such cases, a complex optimization