AUTOMATED MULTISTAGE FILTRATION DEVICE FOR ON-LINE LIQUID ANALYZERS

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Abstract: *A multistage filtration system has been conceptualized, designed, and prototyped. The system is suitable for various types of on-line liquid analyzers. The developed technology resulted to a low-cost, compact, flexible and reliable automatic system that is based on the use of common, low-cost filters combined with a novel, automatic filters replacement mechanism. A general overview of the device is provided and the design procedure that was followed is discussed.*

KEYWORDS*: LIQUID FILTERS, MULTI-STAGE FILTERING, ON-LINE LIQUID ANALYZERS*

1. Introduction

There is a large number of industries that rely on water or other fluids periodic quality analysis for meeting regulatory requirements or for ensuring safety and security for the population. One of the most typical examples is the drinking-water supply industry. Water analysis has become mandatory in residential, commercial, and industrial sectors, and thus water analysis instruments are used for determining the biological, physical, and chemical properties of water. Typically, water quality is assessed only in the laboratory. Samples of water are taken at certain intervals based on diverse regulations in different countries. Lab-based analysis methods of water quality are usually more reliable, but they cannot provide continuous information depicting the real-time data associated with water quality parameters. To safeguard public health, it is necessary to employ a system that can detect and respond to the changes instantaneously. This need has led to the development of real-time monitoring and on-line analysis of water quality, which has become a major trend in today's water analysis instrumentation market [1]. Likewise, the need for on-line analysis of water quality exists in the food industry and the aquaculture industry. The pharmaceuticals industry has similar needs and, in this case, not only for water quality analysis, but also for the analysis of other fluids used for pharmaceuticals production, such as various solvents.

One of the major problems when dealing with on-line fluid analysers is sample filtration. In fact, in the aforementioned examples, the sample cannot be used directly for the analysis. Pre-treatment is required, including a filtration step. Especially for field samples, this is critical since field samples are usually more contaminated than laboratory samples. It is not surprising that contaminants in field samples are reported to be the most frequent cause of problems with on-line analysers [2]. Furthermore, for on-line analysers, sample contamination is also a problem due to the frequency of the analysis. While a laboratory analyser might perform 100 tests a month, an on-line plant analyser could do 100 tests a day. Some technical solutions have been developed and used for overcoming this issue, including self-cleaning filters. Nevertheless, these solutions are very expensive and large in terms of size, thus useful only to specific application fields where cost and size might not be an issue. Most importantly, the lifetime of such solutions is still limited, while in many cases such filters cannot guarantee high retention rates.

Our project answers the need of the on-line analysers industry for a low-cost, compact, flexible and reliable automatic liquid sample filtering device. The overall objective of the project has been to design, develop and verify an automated multistage filtration concept to be used in various types of on-line liquid analysers. The developed prototype device is based on the use of common, commercial filters combined with a novel, automatic filters replacement mechanism and a smart, modular design for combining multiple filtration steps in a single process.

Herein, a brief description of the device is provided considering the limitations due to patenting issues. A systematic engineering procedure was followed for the design of the system, which is also discussed.

2. Design procedure

The system was designed, and detailed engineering drawings were produced using computer-aided-design (CAD) tools. The dimensional compatibility of the individual parts was confirmed using 3D assembly models of the overall device. The CAD drawings were used for manufacturing the prototype through accurate computer-numeric-control (CNC) machining.

For the system development a systematic engineering design procedure was followed, as shown in Figure 1. The procedure starts with the definition of the problem followed by an extensive background research. A thorough market search was carried out and the results revealed that such a device does not exist in the market. It also became apparent that commercially available, filtration systems installed with on-line analysers need constant maintenance and filter changing intervention, which causes significant delays to the overall filtration process. Additionally, some of these on-line analysers, especially when filter changing has to be done in harsh conditions, are prone to error. Furthermore, frequent opening of the device for filter replacement may result to sample contamination.

The next design step was to identify the requirements for the system and prepare a list of specifications which served as a basis for the design (see more details below). Based on the design specifications alternative solutions were generated and systematically evaluated before selecting the most appropriate one, which was developed in detail. Engineering drawings were prepared using CAD software. The prototype was manufactured and then tested following a systematic evaluation procedure (see Section 3). Along the design procedure it was required to return to previous steps and iterate through the process until a satisfactory outcome was achieved.

Design specifications

In general, the system is required to be customizable and adaptable to various application scenarios. The design process includes both the mechanical/electrical parts of the system, as well as the control system. The requirements/specifications also provided a basis for the testing and evaluation of the developed prototype. The requirements were grouped into certain categories:

(1) Functional (multistage filtering operation, use of commercially available continuous filter paper, operation independent of paper porosity / thickness / manufacturer, compactness and transportability of device, high reliability.

(2) Operational (reliable filter paper feeding, cutting, and disposal operations).

(3) Usability (easy/quick installation of the device, intuitive and user-friendly interface, customizable).

(4) Safety (safety-by-design, electrical and mechanical hazards both considered).

(5) General (material selection to meet application requirements and manufacturability, minimize filter paper waste, labelling of cables and components for easy reference).

(6) Control/actuation system (use reliable industrial control electronics and hardware, design to support integration with external devices and expandability).

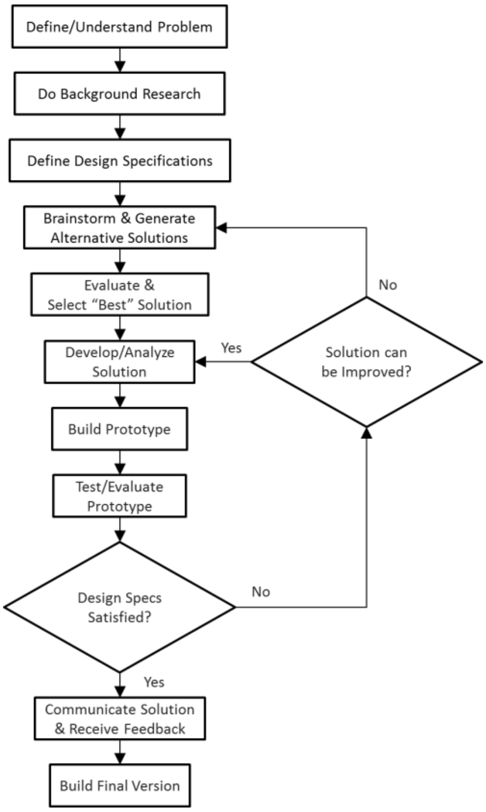

Fig. 1 *General Design Procedure used for the design of the automatic filtering system.*

Materials Selection

The materials were selected based on functional criteria (liquid handling applications), structural requirements, cost and manufacturability. The main materials that were selected were both metallic (aluminum and stainless steel), as well as plastic (POM).

3. Description of the device

Mechanical system

The mechanical system is composed of various subsystems that were integrated together: (i) Structural system (ii) Central multistage filtering module; (iii) Filter cutting; (iv) Filter advance and disposal; (vi) Liquids system. The individual parts are connected together using screws so that the system can be easily assembled and disassembled. Three motors are required for the operation of the device and correspond to the new filter supply system, the filter cutting mechanism, and the filter disposal. Stepper motors were selected for this purpose. The filter paper cutting is performed using a blade that is rolled over a cutting board. On the system it was also included an automated cleaning procedure, which can be performed between filtering cycles by passing water or other cleaning liquids through the system. The overall structure of the system is shown in Figure 2 that includes the mechanical, liquids, and control subsystems.

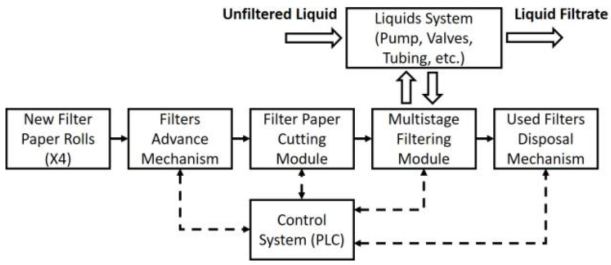

Fig. 2 *Structure of the designed automatic filtering system.*

Control system

Control of the system is based on a programmable logic controller (PLC) which is a reliable and robust industrial option. User interface is implemented through a dedicated touch screen and a user-friendly, intuitive graphics environment. The user can change the functional settings, select between manual and automatic operation, and also test all individual functions of the device. The use of a PLC allows for flexibility and direct integration with other devices. The same PLC can also be used for controlling the pumps that direct the liquid through the filtering system, as well as any valves that may be involved depending on the application.

The general structure of the PLC-based control system is shown in Figure 3. The power supply unit provides the required 24V DC supply to the system. The PLC system comprises the central processing unit (CPU), the memory (where programs and data are stored), and the input/output modules. The latter receive sensory input and send control signals to the actuators (stepper motors), respectively. Communication with the user is via a touch screen and the screen menus that were designed for this purpose.

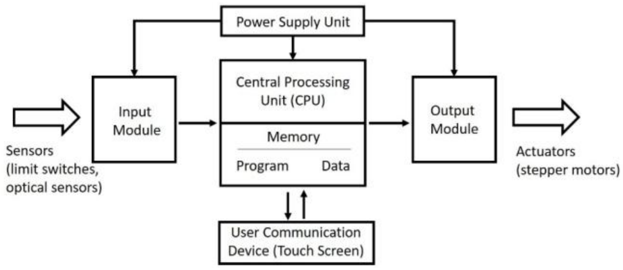

Fig. 3 *Structure of the PLC-based control system of the automatic filtering system.*

3. Testing procedure

Filtration performance is characterized by the pressure drop across a filter and the filtration efficiency. Given that the specific device uses commercial filters from reputable manufacturers, filtration efficiency is ensured. Testing focused on the overall operation of the device itself under realistic conditions.

Initially, various aspects of the device were assessed including the safety and the usability of the device (filter replacement and disposal process, user-friendliness and effectiveness of user interface). The operation robustness was verified by performing repeated cycles in automatic mode. Liquid was pumped through the system using a peristaltic pump, which can supply the required pressure. It was shown that the device can handle different liquid samples including sea water.

4. Conclusions

A multistage filtering system was designed, and the prototype has been developed and tested. A systematic engineering procedure was followed for the design. It is suitable for various types of on-line liquid analyzers and it allows automatic filter changes as well as an automated cleaning procedure. The operation of the system is user-friendly, and integration with other systems is straightforward.

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