SMART VENTILATION SERVING FOR SMART FACTORIES: CHALLENGES AND PERSPECTIVES

Outline of ETC15 workshop

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SMART VENTILATION / SMART AIR TECHNOLOGY FOR SMART FACTORIES

Industry 4.0 is characterised by high levels of sensor implementation, data exchange, computing, and automation. On this basis, it can be assumed that *smart* factories exist, incorporating *smart* ventilation (**SV**) systems, served by *smart* fans. However, the concept of smart industrial fans has not yet become widespread. The probable reason is a stereotype: fans and the related air technical equipment are relatively simple and inexpensive, and thus, they may not deserve sophisticated, smart treatment – in contrast with other types of turbomachinery such as e.g. compressors, gas turbines, and wind turbine farms. The especially large number of fans operated, however, represents a significant impact on global as well as local levels. For this reason, smart fans and smart air technology / SV offer new, practically and economically significant application areas for Industry 4.0.

Some competitive benefits of smart – *versus* traditional – industrial air technology / ventilation are as follows, within the hierarchic levels of fans, equipment, and system. a) Economy in utilized aerodynamic performance; energy-efficient fan operation, enabling savings in operational cost. b) Continuous condition monitoring (**CM**), leading to savings in cost of exchange and repair. c) CM, improving the operational reliability, thus avoiding losses related to malfunction. d) CM, enabling targeted, on-demand, quick maintenance (e.g. in-line, short-term cleaning), thus minimizing losses related to operational break. e) Comprehensive energy management of the factory, for customization of energy consumption of the plant to the available resources, e.g. renewable energy. f) Advanced process control for improved product quality. g) Adaptation to Environmental, Health and Safety (**EHS**) solutions, e.g. low-noise, draught-free heating, ventilation and air conditioning (**HVAC**). h) Adaptation to technologies for Circular Economy, e.g. reusing or recycling.

PRECEDENTS

The above outline was presented at Workshop WS4 of the CMFF'22 Conference [1], referring to paper [2] and presentation [3]. The Workshop was attended by industrial corporations and university experts working in the field of Industry 4.0, turbomachinery, fluids engineering, industrial air technology, industrial ventilation, and HVAC. The presentations and the key topics as well as the outcomes of the consecutive vivid workshop discussion are summarized in what follows.

Utilization of smart fans / ventilation. [4]: A standard, presently non-existing definition for *smart fan* is to be established. For example, is a smart fan a self-learning, self-diagnosing one? The aim of smartness is to be defined – and quantified! – for a given technological system: e.g. CM, energy savings, moderation of downtime. [5]: Various smartness levels and areas of application exist; they are to be identified; analogies can be found from other fields, e.g. "self-driving car" – self-learning fan. The smart features, together with own decision-making, are to be implemented into the control: the fan and the system are at different levels from this perspective. It is to be judged why a smart fan is better and worthier than a "dumb" fan, in context of the entire system. Although a step-by-step evolution is favourable [6], including a smart fan into a non-smart environment may lose the benefits. [7]: A smart system can be only a backup system for several industrial applications. For example, a pump is preliminarily to *work by all means* in many cases, regardless the desirable features of smartness. Opening the system circuit for smart control implementations is risky, raises responsibility issues, and requires qualified personnel. [6]: Self-diagnostics may be combined with automated maintenance, e.g. “self-cleaning”. [8]: Prediction is a key objective in smart industries. [1]: A detailed SWOT analysis (conf. [2]) is needed on SV features.

Adoption of knowledge from other turbomachinery fields to smart fans / ventilation. [4]: Possible smart fans and systems in residential HVAC may be taken for hints. [7]: Vibration sensors are applied e.g. on pump shafts, with colour-LEDs for notifying the personnel. In an oil refinery application, abnormal operation was detected via the changed system noise, as precedent to acoustics-based condition monitoring (**ACM**) [2]. Such techniques still need a maintenance staff. [7], referring to [9]: A standard is available for maximum permissible amount of metal loss from impeller blades due to cavitation pitting in hydraulic machinery; on this basis, specified permissible maximum values: loss of impeller mass [*kg*] or volume [cm^3], depth of blade erosion [*mm*]. Such legislative references may be used as hints for adoption to fans in judging the erosion. [10]: Wind farms and machine learning, steam and other turbines: own and other papers are available at e.g. the ASME Turbo Expos.

Need for acquisition and processing of industrial on-site data. [4]: Training data are needed on real fans. [8]: Industrial on-site measurements for collecting extensive datasets, and retrieving correlations from these real-case data, are essential – even if the collected Big Data are processed consecutively, for gathering *smart* experiences. [5]: Data collection and finding such correlations is a means of “getting rid of comprehensive physics” whereas establishing *smart* control actions.

Need for fan test cases for CM in laboratory environment. [6]: Parallel to on-site measurements, laboratory studies are beneficial, providing well-controlled circumstances for gathering quantified experiences on the CM-related phenomena, supported by literature references. [3]: The means of PLA plastic 3D printing of test fans can be utilized. [3], referring to [11]: Imitation of fan fouling can be carried out using stripes of e.g. electrical tape, stuck on the fan blades. [7]: For predictive CM of the fan and the connected system, in order to gather experiences on degradation (fouling, erosion) / breakdown, it is necessary to artificially “damage fans” and the related equipment in measured laboratory tests. Low-cost rapid prototyping can be used for generating fan samples to be damaged, or imitating degraded / faulty fan geometries, instead of real fans, in scaled-down versions as appropriate. [8]: Such laboratory “damage tests” are to be accelerated, i.e. scaled to a significantly reduced timespan. By such means, laboratory experience can be gathered on fan degradation / damage in a timespan being several orders of magnitudes shorter than the full lifecycle of a real fan.

Sensor type, sensor installation. [3, 10]: In the case of ACM, if the working environment is noisy, it is to be considered to install the microphone(s) *within* the fan unit, as far as the operating circumstances allow for that. Sensors may be included in a protective box / casing. [5, 10]: The sensor types and installations may depend on the industrial application and regulations / legislation, and are to be classified for commercialisation; e.g. dusty gas (cement industry): an in-built sensor would be destroyed, only external installation is suitable. [7]: Installation of any sensors *within* or *in the vicinity* of fan units is risky from the viewpoint of disturbed flow zones (e.g. duct bend close upstream); i.e. compromises are to be found in installation. [4]: The necessity of periodic sensor calibration and sensor durability are constraints that usually tailor the sensor type and installation.

DIY sensors for fans. [3]: Low-cost Do-It-Yourself (**DIY**) sensors in an Internet-of-Things (**IoT**) approach; enabling WiFi / Bluetooth connection; serving for Big Data / machine learning; data processing e.g. using MatLab libraries; pressure transducers / condenser microphones from 1 *Hz* to

20 k*Hz* (with limits). [3] referring to [11]: fan blade fouling detection using a DIY dynamic microphone; both time-domain and FFT analysis; Reconstructed Phase Shape (**RPS**) analysis, showing the signatures of fouling in a throttling-dependent manner. This example suggests the applicability of ACM [1-2]. [7]: Sensor calibration is a critical topic. It is to be assessed in a critical view how a low-cost DIY sensor may fulfil the demands of post-calibration reliability, as well as durability (sufficiently long lifetime), and warranty. [6]: Sensors of some EUR price are needed, enabling the installation of multiple sensors if necessary. [7]: The number of installed sensors is to be sufficient but is to be purposefully limited, for a reasonable data processing, and for avoiding redundancies. [4, 8]: The benefit of low cost of a DIY sensor may be counterbalanced by the drawback of risk of sensor damage and need for its replacement.

Future commercialisation of smart fans. [5]: It is to be decided whether the smart feature – including the sensor – is built in the fan, thus making up a new integrated product, or is an add-on that can be purchased in addition to the fan already existing on the market. [12]: The industrial exhibitor presented an axial fan unit incorporating an "add-on" integrated flow rate and pressure meter, thus acting as a smart fan candidate. [4]: As *starting point*, a *candidate toward a smart fan* may be considered as a fan equipped with industry-specific instrumentation and data processing integrated in the fan unit for *fan CM*, thus forming an independent commercial product. Ambitioning smartness in the entire connected technological system can be a next phase. [12-13]: From this perspective, vibration monitoring is of especial interest for axial [12] and radial [13] fans. [5]: Relations with legislation are to be treated: legal tick mark is to be put on the smart product; impact on aging (e.g. sensor durability), maintenance, and warranty are to be considered in the service contract.

WORKSHOP PLAN

The ETC15 Workshop, being a further development of the CMFF'22 Workshop [1], is planned as follows. A short and provocative introductory presentation by J. Vad is to stimulate and orient the Workshop, illustrated by industrial examples, referring to manufacturers' products that can be personally viewed at the venue of the Conference. Companies contribute to the Workshop as manufacturers of candidates of smart air technical elements, such as axial fans [12] (exhibitor), radial fans [13] (exhibitor), and perforated textile air ducts [14] (sponsor). The examples incorporate market survey on sensors; fan vibration monitoring using DIY sensors; possibilities of integration of sensors into fans [12]; ACM on fans [13] and on airduct systems [14]; air technical systems with quick and low-cost targeted maintenance [14], as illustrated by portable elements presented at the Workshop.

The short introductory presentation is followed by a vivid discussion and exchange of views on the Workshop topics by the audience. Industrial representatives and university research experts from various turbomachinery fields – NOT fans only! but also others, for a synergic approach – are very welcome at the Workshop, in order to add to the State of the Art regarding challenges and perspectives in smart fans / ventilation / air technology. Some of the key topics to be discussed on industrial SV are envisaged as follows, for further development of findings outlined in the Precedents section.

How to define and realize a commercial smart fan product? How to design, run and utilize parallel on-site and laboratory campaigns for SV? How to make compromises in sensor techniques – sensor types and installations – for SV, optionally involving DIY devices? What are the convincing, quantified benefits – e.g. improvements in percental numbers – for manufacturers and industrial users for SV? Are there any legislative references compelling fan manufacturers / users moving toward SV? How to protect the intellectual property related to solutions elaborated for SV? How to co-operate for establishing e.g. EU-funded projects on SV?

The oral contributions by the workshop participants will be documented. On this basis, the summary and conclusions of the Workshop will be elaborated and distributed in written format past the Conference, referring to the named contributors, similarly to the structure of the present Outline.

REFERENCES

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[2] Tóth, D., Vad, J., (2022). *Industry 4.0 perspectives of axial and radial fans in smart industrial ventilation: conceptual case studies.* Proc. Conference on Modelling Fluid Flow (CMFF'22), Budapest, Hungary. Paper No.: CMFF22-040.

[3] Dr. Delibra, G., *Industry 4.0 in smart ventilation: cost-effective "Do-It-Yourself" (DIY) sensors.* Presentation at Workshop [1].

[4] Dr. Kádár, B., managing director, EPIC InnoLabs Kft. (Ltd.). *Oral contribution to discussion at Workshop* [1].

[5] Schreck, G., managing director, futureWorks Solutions. *Oral contribution to discussion at Workshop* [1].

[6] Dr. Horváth, Cs., Department of Fluid Mechanics, Faculty of Mechanical Engineering, Budapest University of Technology and Economics. *Oral contribution to discussion at Workshop* [1].

[7] Dr. Benigni, H., Institute of Hydraulic Fluidmachinery, Graz University of Technology. *Oral contribution to discussion at Workshop* [1]*, and written personal communication.*

[8] Zipszer, G. CFD engineer, eCon Engineering Kft. (Ltd.) *Oral contribution to discussion at Workshop* [1].

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[11] Corsini, A., Tortora, C., (2016). *Fouling detection in low speed fan using near-field DIY sound pressure sensors.* ASME Paper GT2016-57557.

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[14] Sándor, D, managing director, DAAL-CON Kft. (Ltd.) *Attendance at Workshop* [1]. *The company acted as industrial exhibitor at CMFF'22*.