Study on Multihole Pressure Probe System Based on LabVIEW
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Abstract
The multihole pressure probes are widely used to determine flow velocity vectors and pressures in the fluid machinery fields due to their robustness, convenience, and economy in flow measurement. Accuracy and fast calibration of a multihole pressure probe is very important. In this article, a multihole pressure probe automatic calibration system is developed. The hardware device mainly consists of computer, motion control equipment and data acquisition (DAQ) equipment, and the software program is developed using the G-language based on LabVIEW platform. The fundamental theory and method of multihole pressure probes is reviewed, as well as about how to take into account the compressibility effect of the fluid. The developed system can be easily integrated by engineers in research institutes or industries, without requiring more expertise in programming or multihole probe measurement method. Furthermore, the system is used for a five-hole probe’s calibration and measurement, satisfactory results are obtained. 0.5° is the maximum uncertainty for the flow angles and 1.7% is for the velocity magnitude. The measurement biases being caused by the effect of Reynolds number are investigated. In the Reynolds number range of $1.06 \times 10^4$ to $4.29 \times 10^4$, the measurement biases of velocity vector are presented.

Introduction
It is vital to measure and understand the flow behaviors in the turbo-machinery, such as pump, water or steam turbine, turbo-compressor and so on, where the flow has severe three-dimensional (3-D) and unsteady characteristics.\(^1\) There are many instruments to measure the flow velocity fields. Hot-wire & hot-film anemometry (HWFA), Laser Doppler velocimetry (LDV), and particle image velocimetry (PIV) are the most advanced popular instruments. The HWFA is very delicate, has high spatial resolution and high frequency-response characteristics. It is commonly applied to measure the velocity magnitude, direction, and frequency components of a fluctuating velocity, but its sensing element are very fragile and sensitive to contaminate.\(^2\) The LDV allows contactless measurements, and has an excellent spatial resolution and a linear response characteristics.\(^3,4\) The PIV also allows contactless measurement, and is capable of measuring a 2-D or 3-D velocity vector fields in a given space at a certain instant. The PIV can gain a near continuous velocity field, so it has a high space resolution. But due to the limitation of the computer picture data transmission capability, it has a low time resolution. When using the optical instruments such as the LDV and PIV, the adjustment on the light beam or the piece of light sources could be arduous, and that demands keeping a good light transmission through the flow field, as well as seeding proper tracer particles in the flow field. The high price is another reason to limit the wide use of the LDV and PIV.\(^5\) So the traditional measurement technique, namely pressure probe technique, is necessary to be developed.

Pressure probes are the instruments to measure flow velocity and pressure. Their capabilities are often preferred over the above optic systems due to the simplicity in operation and maintenance, relatively low cost and the robustness in applications.\(^6,7\) In fact, pressure probes are widely used in the turbo-machinery fields, where their reliability is...
well-recognized.\textsuperscript{6,8} Two-dimensional flow velocity can be completely determined using three-hole probe devices, while four or more hole probes are necessary to characterize 3-D velocity vectors.\textsuperscript{6,8–10}

Actually, many researchers have done or are doing about the multihole pressure probe’s application. The performance of a probe depends not only on its own characteristics such as the head geometry, holes number, hole angular location, sensitivity, but also on the characteristics of the measured flow field.\textsuperscript{11,12} Diego researched the effect of the head geometry of the probe (cobra, trapezoidal, and cylinder probes were included), as well as the effect of the flow field factors, such as Reynolds number, Mach number, turbulence intensity, velocity gradient effect, and wall proximity effects.\textsuperscript{13} He directed that the head geometry of the probes and the Reynolds number are the most important factors influencing the calibration of pressure probes, furthermore the behavior of the probe also depends on the Mach number as well as the turbulence intensity. Argüelles Díaz et al. developed a zone-based method for calibration data reduction aiming at extending the angular range of a three-hole probe, then the effect of the head geometry, construction angle, Reynolds number, and turbulence level were studied using the method.\textsuperscript{6,9,14,15} It is known that, fewer holes can get smaller geometry of a probe. So in order to reduce the probe invasive influence on the flow, many attempts were made to reduce the size of probe head and to achieve the compact construction of the probe. But the larger seven-hole probe was also designed for its measurement capability in larger angular range.\textsuperscript{10}

In addition, many efforts were made to improve the accuracy of multihole probes’ calibration. The approach Everett et al.\textsuperscript{16} took is to use a nearest neighbor interpolation of the calibration data rather than curve-fitted polynomial expressions. Hshootman and Bannink\textsuperscript{17} used the advanced 3-D curve-fit analysis programs to obtain relatively simple analytical expressions for the four calibration coefficient functions of the five-hole probe, which compensate for nonsymmetric probes and smooth out the effects of bad data points. Pisasale and Ahmed\textsuperscript{18} developed a novel way of nondimensionalized calibration coefficients by replacing the denominator of the calibration coefficient with other modified pressure differences, this method successfully overcomes the problem of singularity encountered in the traditional method and extends the range of probe’s pitch and yaw angles.

Measurements on unsteady flow are also an important application for the multihole probe. Matsunaga et al.\textsuperscript{19} designed a new five-hole probe combining with a pressure transducer for measuring 3-D unsteady flow, and a calibration procedure was used to reduce the inertial effect due to the change in flow velocity, a satisfactory accuracy could be achieved. Argüelles Díaz et al.\textsuperscript{14} developed a dynamic probe with three miniature pressure sensors being placed inside axial y, and compared the new data reduction technique with the traditional one.

All the above researches in industries and research institutes show the extensiveness and practicability of the multihole probe applications. However, it is well known that the probes must be accurately calibrated before they are used to measure the unknown flow field. Manual operation to carry out the probes’ calibration is time consuming, and susceptible to the artificial factors. To raise the calibration efficiency and measurement accuracy, an automatic calibration system is necessary. However, few reporters presented the details about how to build up such a calibration system effectively, so a relative complete presentation on developing such a system is very valuable, especially on how to configure the hardware and how to develop the software. Such a relative complete presentation is one of the goals of this article. In this article, a multihole pressure probe’s calibration system is developed, including the hardware and software. To improve the efficiency of developing the system, conventional hardware devices are chosen as many as possible, and the well-known LabVIEW programming platform is utilized.

LabVIEW has been used successfully for many years in test and measurement applications due to the ease of graphical programming, comprehensive function of data acquisition (DAQ) and signal processing, as well as its strong capability of interconnecting directly with instruments, sensors, and actuators, so many different types of instruments and buses can be available on the LabVIEW platform.\textsuperscript{20}

In this article, the configuration of a five-hole probe calibration system is detailed in order to give a reference about how to build up a multihole pressure probe calibration system. First, the fundamental theory of multihole pressure probe technique is reviewed. Then the requisite hardware devices and software development details are formulated taking a five-hole pressure probe calibration system as an example. Finally, the system is used to calibrate a five-hole spheric probe, and the calibrated probe is applied into measurement. The acceptable uncertainties of the measurement result are presented; this also verifies the availability of the system. And the effect of Reynolds number on the probe’s calibration and measurement is investigated by using the system.