A Video Probe Measurement System for Coarse Water Droplets in LP Steam Turbine

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Abstract. A video-probe measurement system has been developed at IPTFM. Designing process and test results of the system are described in detail in this paper. The measurement system mainly consists of camera module (XC-HR70), frame grabber (Matrox Meteor-II/Multi-Channel), function generator and image acquisition and processing interface. Static and dynamic experiments on water droplets were carried out on the spraying platform. During the static calibration testing, standard glass beads were used to obtain the parameters. And test results showed that this method has good repetition and credibility. During the dynamic testing, spraying experiments were carried out. The size and velocity of spray droplets were measured, which showed good agreement with the known empirical value. Both dynamic and static testing results show the measurement system is capable of online measuring the coarse water droplets in low-pressure steam turbine and obtain the size and velocity of water droplets from images snapped by the system.

1. INTRODUCTION

For the large power plant, the inlet steam of turbine is superheated, and mixed by fine and coarse water droplets in the LP cylinders and condensers, which will decrease thermal efficiency, cause dangerous corrosion of turbine blades and influence the operation safety. Researches on the water droplets measurement could enhance the basis investigation of the blade water corrosion model, as well as predicted the corrosion areas and provided information for precautionary measures.

For the fine droplet, the global method, known as the extinction method has been chosen to obtain its size distribution and concentration (wetness). Several optical probes based on this measurement principle have been developed(Cai Xiaoshu, et al., 2001; Ross, et al., 1994). Up to now, however, there is no universal measuring method available for CWD (coarse water droplet). EDF in France has developed a Holography probe and a Microvideo probe to measure the size and velocity of CWD (Kleitz A, et al., 1991). In Germany and Japan, the side scattering method is employed to obtain the size of CWD(Bohn D, 1997; Tanuma T, 1991). "Catchpot" probes were developed in Britain and Czech to measure the amount of CWD(Williams et al., 1976; Petr et al. 1995). However, it is still not very clear about the properties of CWD as well as its proportion in the total wetness. In order to better understanding the mechanism of erosion of blades and to determine the total wetness accurately, it is necessary to measure size, velocity, concentration and amount of CWD.

Digital imaging is becoming increasingly attractive because of the availability of low-cost high performance imaging devices and computing hardware. An advantage of using the imaging approach is that non-intrusive real-time measurement of many individual particles can be measured concurrently and continuously.
For measuring the CWD in steam turbine, a video-probe measurement system has been developed at IPTFM. Designing process and test results of the system are described in this paper.

2. VIDEO PROBE MEASUREMENT SYSTEM COMPONENTS

The measurement system mainly consists of camera module (XC-HR70), frame grabber (Matrox Meteor-II/Multi-Channel), function generator and image acquisition and processing interface (shown in Fig.1 and Fig.2). XC-HR70 is an ultra-compact monochrome camera module ideal for high-resolution image capturing applications. A 1/3 type progressive scan CCD incorporated in the XC-HR70 allows the output of XGA resolution (1024 x 768) images at a rate of 30 frames/s. By inputting an external trigger signal, one can capture the information of single screens at arbitrary timing. In this system, the minimum exposure time can be set as short as 10μs. That is very important for capturing the fastest moving CWD.

3. SYSTEM CALIBRATION

System calibration is very straightforward and is realised off-line by the use of a low-cost precision lined reticule whose smallest division is 100μm. During the calibration, the video probe is set on the optical rail. The lined reticule is put in front of the camera and the reticule is perpendicular to the camera. Move the reticule forward and backward and get the corresponding reticule images. When the reticule image is sharpest (as shown in Fig. 3), the distance between the reticule and the lens is defined as the standard working distance. In this system, the standard working distance is 11mm. From Fig. 3, it can be found the field of view is 3.9mm by 2.95mm at the standard working distance. With the fact that the image size is 1024 x 768 pixels, it can be noted that one pixel corresponds to 3.8μm (scaling...
factor). The calibration is automatically accomplished in the software and the scaling factor obtained will be used in the process of measuring the size and velocity of droplets.

4. STATIC TESTING

After the system calibration, the static testing is carried out. Three kinds of standard particles whose mean diameter are $39.0 \pm 2.1 \mu m$ (particle A), $56.4 \pm 2.2 \mu m$ (particle B), and $77.2 \pm 4.2 \mu m$ (particle C) respectively are chosen for the static testing. The particle images and the measurement results are shown in Fig.4-Fig.6. The statistics samples of three kinds of particles are 526, 574 and 223 respectively, and the corresponding measurements of mean diameter are $36.78 \mu m$, $55.26 \mu m$ and $72.43 \mu m$ respectively. So the measurement errors are -5.69%, -2.02% and -6.18% respectively. The measurement results agree well with the known values.

![Image of particle A](image1)

**Fig.4** The image and the particle diameter distribution of particle A

![Image of particle B](image2)

**Fig.5** The image and the particle diameter distribution of particle B
4. DYNAMIC TESTING

4.1 Spray Testing Set-up

The spray testing system is composed mainly of video probe, nozzle, triplex plunger pump, and water tank (as shown in Fig.7). The water from the tank is thus pressurized as it goes through the plunger pump and atomized at the nozzle exit. The spray droplets size relates to flow rate, and water pressure. The larger water pressure yields smaller droplet and vice versa. The type of spray nozzle used in testing is Danfoss 45°S, and its design flow rate is 2.75gal/h. The flow pressure is 0.6 MPa.

4.2 Size Measurement of Spray Droplets

Figure 8 shows the measurement results and Figure 9 shows the images of droplets. The total number of water droplets is 971, and the mean diameter is 73.98μm. The diameter of water droplets range from 10μm to 400μm, but mainly distributed from 10μm to 50μm.

Fig.6 The image and the particle diameter distribution of particle C

Fig.7 Schematic diagram of the spray testing system

Fig.8 Particle diameter distribution of spray droplets
4.3 Velocity Measurement of Spray Droplets Based on a Single Motion Blurred Image

When the exposure time of the camera becomes longer or the velocity of water droplet becomes faster, it is difficult to get the sharp image of droplets. The image becomes blurred and it shows the trajectory of the water travelling in the exposure time (as shown in Fig. 10).

Assuming the length of trajectory of the spray droplet is $L$, the diameter of the spray droplet is $d$, then the displacement of the spray droplet during the exposure time $t$ can be expressed as $S = L - d$ and the velocity of water droplet can be given as

$$ v = \frac{S}{t} = \frac{L - d}{t} $$

For the droplet shown in Fig. 10, $t = 50\mu s$, $L = 95 \times 3.8 = 361\mu m$, $d = 35 \times 3.8 = 133\mu m$, so the velocity is

$$ v = \frac{(361 - 133)\mu m}{50\mu s} = 4.56 m/s $$
Fig. 11 shows the motion blurred image of spray droplets when the flow pressure is 0.6 MPa. By the analysis of the Fig.11, it can be determined that the total number of spray droplets is 272 and their average velocity 1.64m/s and their average diameter 67.87 μm. The velocity distribution of spray droplets is shown in Fig.12. It can be seen from Fig.12 that the velocity of spray droplets mainly distributed in the range of 0.5m/s–3m/s.

5. CONCLUSIONS

In this paper, the designing and testing of a video-probe measurement system for coarse water droplets are described in detail. Experiments on static and dynamic water droplet were carried out on the spraying platform. During the static calibration tests, standard glass beads were used to obtain the parameters. And testing results show that this method has good repetition and credibility. During the dynamic tests, spraying experiments were carried out. The size and velocity of spray droplets were measured, which show good agreement with the known empirical value. Both dynamic and static test results show the measurement system is capable of online measurement of the coarse water droplets in low-pressure steam turbine and obtain the droplet size parameters from pictures snapped by the system.

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