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The inner-cone angle measurement of aero-engine nozzle based on conoscopic holography

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ABSTRACT

The geometry of aero-engine nozzle has a significant impact on its working performance. In this work, the conoscopic holography is employed to measure the inner-cone angle of aero-engine nozzle in a noncontact way. For such purpose, a five-axis coordinate measuring machine, the experimental platform, is built. Its measuring mathematic model is established afterwards according to multi-body kinematics. The objective function of least square fitting on conic surface is defined in terms of parameterized vector of cone, and Levenberg-Marquardt algorithm is used for solving its unknown geometric parameters. Finally, the experimental results demonstrate that the adopted method in this work is feasible and high-precision. The measuring repetitive error of conic angle is within 0.0019°.

1. Introduction

The fuel nozzle, a key part of aero-engine, has a direct influence on the working performance of aero-engine [1]. A range of computational and experimental works have been developed to reveal the relationship between the geometry parameters (e.g. nozzle shape, diameter, surface roughness, length-diameter ratio, conicity level etc.) of nozzle and its related performance parameters (e.g. atomization angle, fuel mixing and consumption, stability of the combustor, exhaust emission and noise reduction etc.) [2–9]. Among these geometrical parameters, the effect of conic angle is particular one which can't be ignored. Consequently, it is of great necessity and urgency to develop high-precision measuring technologies with respect to cone angle of aero-engine.

Regarding how to inspect an inner cone angle, various conventional techniques and their variants are still popular on many occasions, such as, universal angle meter, sine-ruler meter, dual-ball method, conic gauge, go-no go gauge and their combination [10–14]. Unfortunately, although they are easy-operated and low-cost, none of them is competent for such testing situation of high precision and automaticity. Liu Xingrong et al. presented a practical technique to obtain the cone angle in terms of 5″ repeatability error by virtue of inspecting the inner diameter difference using a length-measuring instrument, SUPRA500, coming from HELIOS corporation in Germany [15]. Whereas, it is difficult to inspect small-size components with cone feature. Based on the similar principle, Yang Zelin set up an automatic sensor mechanism with a mobile big-end disc and a mobile small-end disc serving the purpose of getting the big inner diameters and the small one of cone hole accordingly. With the help of the flexible supporter, the work piece can do free movement horizontally following the big and small discs so as to keep concentric between discs and cone hole [16]. In this case, the machining accuracy of discs will affect the measuring result directly, and the contact force between the discs and cone surface has to be controlled precisely and consistently. Coordinate measuring machine (CMM) is capable of testing cone hole in two different ways. One is that the cone angle can be deduced from the diameter difference of the sectional circles, in such

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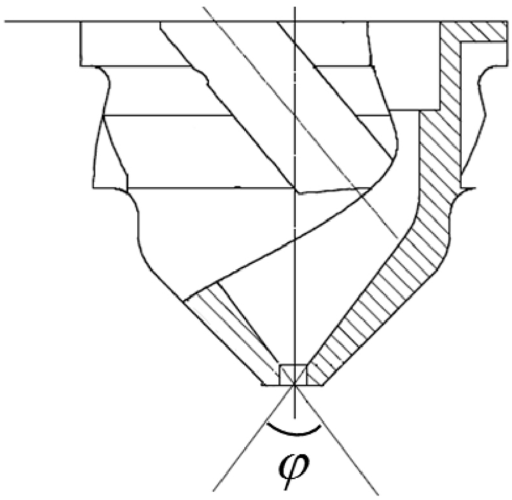

Fig. 1. The structure of nozzle.

case, the cone surface should be aligned correctly. The other is that the cone angle can be calculated by fitting those 3D coordinates collected from cone surface. The testing error of CMM, the pick-up strategy of surface points and the fitting method will generate a noteworthy impact on the final output jointly under this circumstances [17].

This work attempts to focus on the inner-cone angle measurement of a so-called single-circuit single-outlet aero-engine nozzle shown in Fig. 1. A five-axis coordinate measuring machine is designed and built as the experimental platform. A laser probe is employed to gather the points of conic surface in a noncontact way based on conoscopic holography. The rest of this work is organized as follows: Section 2 focuses on the introduction of the working principle of conoscopic holography. Section 3 represents the least square fitting method on conic surface. Section 4 gives a brief introduction on the overall configuration of experimental platform and specifies how to set up its measuring model. Section 5 conducts a discussion on the experimental results.

2. Working principle of conoscopic holography

The conoscopic holography is originally proposed by G.Y. Sirat and D. Psaltis, who work for California Institute of Technology in 1985 [18]. Its working principle is illustrated in Fig. 2. The laser beam emitted by laser unit 9 goes through the collimating beam expanding system 10 and enters polarizing beam splitter 4. After that, the beam converges on the surface of tested object 1 via the $\lambda/4$ slide 3 and lens 2. The conoscopic beam reflected by object gets into uniaxial crystal 6 via lens 2, $\lambda/4$ slide 3, splitter 4 and $\lambda/4$ slide 5, here conoscopic beam has been split into two beams, so-called ordinary and unordinary lights, by the birefrigent effect of uniaxial crystal 6. The interference caused by such two split beams occurs after they passes through polarizer 7. Finally, the CCD camera captures the holographic stripe image. The intensity of interference fringes could be expressed as following.

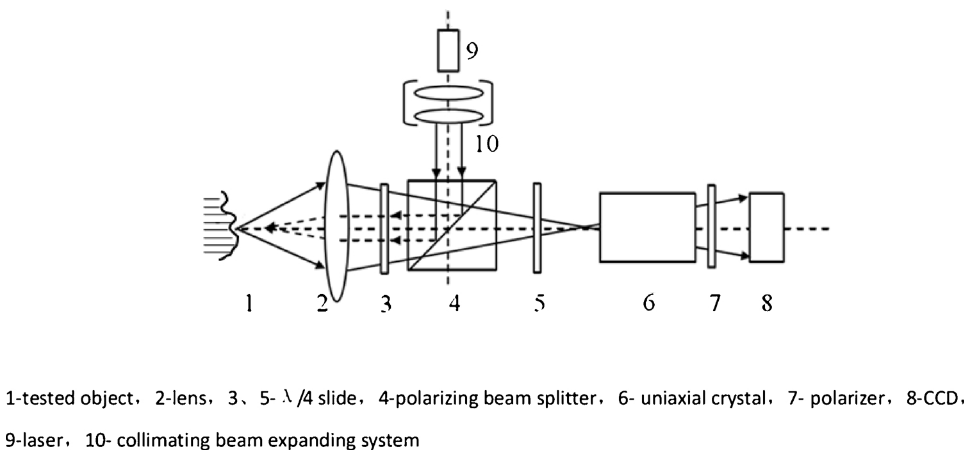

Fig. 2. Light-route configuration of conoscopic holography.