Materials Science Forum Vols. 532-533 (2006) pp. 1-4
online at http://www.scientific.net

A Study on Driving Interference-fit Fastener Using Stress Wave

Zengqiang Cao[1,a] and Qinghua Qin[2,b]

[1]Faculty of Mechanical & Electrical Engineering, Northwestern Polytechnical University, Xi'an 710072, China

[2]Department of Engineering, Australian National University, Canberra, ACT 0200, Australia

[a]czq66326@nwpu.edu.cn, [b]qin.qinghua@anu.edu.au

Keywords: Fastener, Interference-fit, Stress-wave, Driving

Abstract. Interference-fit fasteners are used in large numbers throughout aircraft structures. Conventional installation methods are driving fasteners into aperture using pneumatic or hydraulic tooling, installation damage always occurs using these methods. This paper introduces a new method of driving interference-fit fastener using stress wave, reports on a comparison of driving quality between stress wave driving and hydraulic force driving. The experiments completed by authors indicate that stress-wave method can drive the fasteners with larger interference which conventional installation method can not implement; stress wave driving method provides high installation quality and repeatable results compared with the conventional driving method; and stress wave driving method is convenient to be used. The experiments prove that the protuberant material produced by stress wave method is less than that of conventional installation methods, this is advantaged to improve the fatigue strength of joint.

Introduction

Interference-fit fasteners are used in large numbers throughout aircraft structures. The majority of interference-fit fasteners are manually installed using pneumatic or hydraulic tooling now. These techniques have the following disadvantages: the fastener may yield and expand so that it is prevented from being completely driven into aperture or even if so driven it may cause galling and gouging; for metal fasteners with large interferences, for example, when relative interference is more than 1.0%, hammering methods are ineffective and dangerous. The large hydraulic cylinder apparatus can be used if space is available to provide the necessary operating clearance and support, but handheld hammering tools have to be used sometimes being of structure limit. Letheris[1] first filed a patent of driving interference-fit fastener using stress wave, and pointed out this driving method could overcome the disadvantages of hammering methods. Tao[2] studied the driving process of 30CrMnSiA interference bolt using stress wave, but fatigue test results were not ideal. Being of the limitation of high voltage stress wave apparatus, the stress wave driving method was not implemented in production for a long time.

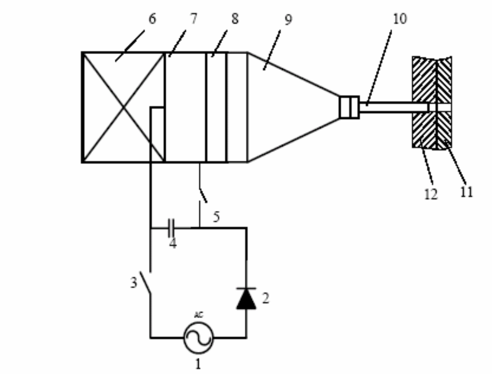
Zieve[3] invented the low voltage electromagnetic riveter in 1986, solved the problems what high voltage stress wave apparatus had, then electromagnetic riveting technique was spread in a number of different aircrafts. To extend the electromagnetic riveting technique, Electroimpact Inc. and British Aerospace studied together lockbolt installation using low voltage electromagnetic riveter (EMR). Studying indicated that lockbolts installed by EMR can achieve or exceed the lockbolts installed by current installation in terms of pre-load, lap shear fatigue life, and static shear strength [4]; in contrast to using the manual driving methods, using electromagnetic riveting system for lockbolts driving significantly reduces assembly time, and also provides repeatable results. Electroimpact Inc. developed lightweight handheld electromagnetic riveter HH50 in 2002, then electromagnetic riveter becomes convenient to install interference-fit fasteners.

The paper reports on an investigation involving a comparison between stress wave driving method and conventional driving method. Results are presented on the installation quality, interference, protuberance height, etc.

The Principle of Driving Fastener Using Stress Wave

Stress waves are a form of energy transfer which causes motion within a solid. When we are considering the effects of forces which are applied for only very short periods of time, or are changing rapidly, the effects must be considered in terms of the propagation of stress waves. If an arbitrary small disturbance is originated within a restricted portion of an elastic solid medium, neighboring portions will soon be set in motion and thrown into states of strain. According to stress wave theory, when a fastener is impacted, stress wave imparts a high particle velocity in the direction of propagation of the wave and simultaneously increases the stress in the fastener. The axial momentum of the fastener, produced by the propagation of the stress wave through the fastener, causes a tensile elongation in the direction of propagation and a contraction at right angles to the direction of propagation. This tensile elongation or expansion is governed by Poisson's ratio which is the ratio between the lateral strain and the direct tensile strain. The stress wave reflected from the remote or free end of the interference fastener is a tension wave and the outward velocity of the free end is doubled to drive or draw the interference fastener into the receiving aperture.

Driving interference-fit fastener using stress wave needs a stress wave device, as shown in Fig.1. Initially, the capacitor bank 4 is charged by power supply 1 when recharge switch 3 is closed. After the capacitor bank is charged, switch 3 is opened and discharge switch 5 is closed thereby transmitting a high amperage current pulse, of short duration, through electromagnetic coil 7. A high intensity magnetic field is set up around the coil and this field intersects the drive coil 8, which acts as a one turn secondary winding of a transformer, thereby inducing a current therein. The induced current flowing through the surface of the drive coil sets up a high intensity magnetic field within the driver coil. The electromagnetic repulsion established by the interaction of the two high intensity magnetic fields generates a stress wave in the drive coil which is propagated through the conditioning means 9 into the fastener 10.The stress wave, propagates from left to right as a compression wave in the fastener with a velocity V, reaches the remote or free end of the fastener and reflects as a tension wave with a velocity of 2V outward in the axial direction. If the length of the pulse is sufficient, i.e., greater than the length of the fastener, the entire fastener is set in motion with a velocity 2V. This momentum imparted to the remote end of the fastener is sufficient to overcome the static forces of friction between the receiving aperture and the fastener to drive or draw the fastener into the receiving aperture. After each discharge of the capacitor bank the fastener is partially driven into the aperture by overcoming the frictional forces.



1 power supply, 2 SCR, 3 recharge switch, 4 capacitor bank, 5 discharge switch, 6 shock absorbing means, 7 electromagnetic coil, 8 drive coil, 9 conditioning means, 10 fastener, 11 and 12 stack panel

Fig.1 Schematic representation of stress wave device

Installation Quality

Protuberance Height Comparison. During the driving of interference fasteners, some stack materials will be shoved to exterior of the stack, it is so-called “protuberance”. Being of protuberance, fastener head cannot contact close stack materials, and clearance between stack and fastener head will be engendered, contacting stress is centralized to protuberance, the fatigue life of joint is reduced. So, the protuberance is an important term of analyzing installation quality, the protuberance should be reduced to improve joint quality.

To compare the protuberance height of different installation methods, some cold-working implemented by hydraulic squeeze and stress wave hammering have been completed. Table 1 is the protuberance heights produced by these two driving methods. It is indicated that, in the same level of interference, protuberance height produced by stress wave method is less than that of produced by hydraulic and pneumatic methods. There are two reasons, the first, during driving, fastener is shrunk in radial being of stress wave propagation, the forces of friction between the receiving aperture and the fastener is less, so little material is shoved to exterior; the second, the driving time of stress wave is very short, about in 1 ms, there is not enough time to make the materials to be shoved to exterior. But the driving time using hydraulic and pneumatic tools is about several seconds, much more materials are shoved to exterior.

Table 1 Protuberance heights of different methods

Stack material		Hydraulic squeeze [mm]	Stress wave [mm]
30CrMnSiA	2 layers	0.05	0.02
	3 layers	0.06	0.04
LY12CZ	2 layers	0.07	0.03
	3 layers	0.09	0.05

Metallurgical Examination. A fastening process is evaluated by the quality of the produced joint. The term quality is defined by a number of parameters such as strength and microstructure in and around the joined material. These parameters are directly related to a joint’s fatigue life and corrosion resistance in service. Fig.2 is the microstructure of aperture wall material produced by stress wave method and hydraulic squeeze method.

From Fig.2, it is shown that aperture wall materials have a certain thickness of plastic strain in radial. Flow direction of aperture wall material produced by hydraulic squeeze method is more obvious than that of produced by stress wave method, more material is shoved to exterior, so its protuberance height is larger. In addition, the crystal diameters of aperture wall material of joint produced by stress wave method is less than that of hydraulic squeeze method, crystal was slenderized, which is advantaged to improve fatigue life of joint.

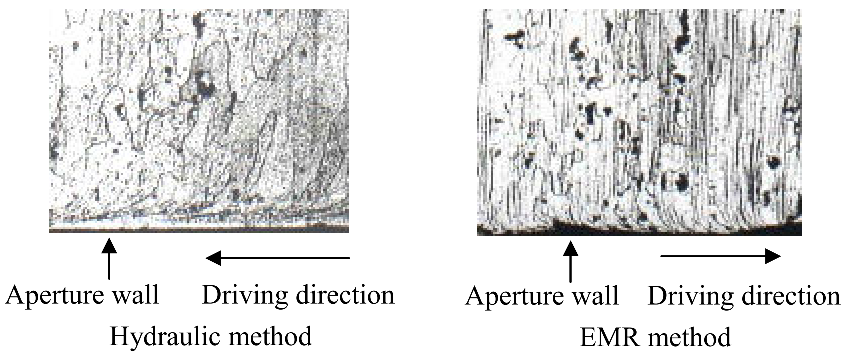


Fig.2 Microstructure of aperture wall material

Driving Force Comparison

Being of stress wave propagating, fastener shaft is shrunk, the driving method using stress wave needs lesser driving force than traditional driving methods. Table 2 is the comparison of driving force between stress wave driving and hydraulic driving. Stress wave device can change driving force easily by adjusting recharge voltage, increasing recharge voltage will increase driving force; decreasing recharge voltage will decrease driving force. When recharge voltage is fixed, the driving force is determined, so stress wave method provides repeatable results.

Table 2 Driving forces of different methods

Stack material		Hydraulic squeeze [KN]	Stress wave [KN]
30CrMnSiA	Interference 1.2%	14	9
	Interference 1.77%	17	11
LY12CZ	Interference 1.2%	8	7
	Interference 1.77%	11	9

Interference Comparison. The traditional driving methods can only driving fastener with less interference, in general, the interference should no more than 1% [1]. To prevent damaging to structures, fasteners with large interference are always frozen before installation, and the driving process is complex, and the driving cost is high. The most important is that the traditional driving methods can not achieve the best fatigue life being of adopting less interference. In theory, being of elasticity shrinking, the increased interference driving fastener by stress wave can achieve to material elasticity limit, so the driving method using stress wave can complete the installation of fasteners with large interference. NSNA Ti-6Al-4V highlock bolts with 6.31mm diameter have been installed using stress wave methods, the relative interference were 1.77%, as shown in Fig.3.

Fig.3 Installed interference bolts using stress wave (1.77% interference)

Conclusions

The driving method using stress wave can complete the installation of fasteners with large interference.

Comparing protuberance height and material microstructure, the driving quality using stress wave is higher than that of traditional driving methods.

The driving method using stress wave needs lower driving force than traditional driving methods.

References

[1] B.P. Letheris: *Method and Apparatus for Driving Interference-fit Fasteners*, US Patent: 3945109, (1974).

[2] H. Tao, G.F. She and X. Sheng: ACTA Aeronautica et Astronatica Sinica, (1993) No.8, pp.439-442.

[3] P.B Zieve: *Fastec West '86*, Anaheim, October, (1986).

[4] S. Smith: *SAE Aerofast'2000*, New Orleans, LA, September, (2000).