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A versatile split Hopkinson pressure bar using electromagnetic loading

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ABSTRACT

This paper presents a novel electromagnetic split Hopkinson pressure bar (ESHPB), which employs the electromagnetic energy conversion technique of LC circuit to generate directly the incident stress pulse.

Such a versatile technique can generate easily compressive as well as tensile incident pulses. The duration and amplitude of the incident pulse could be controlled by adjusting the capacitance and charging voltage in the LC circuit. Therefore, compressive or tensile high strain-rate tests can easily be performed using the present apparatus by simply choosing the compression bars or tension bars.

The primitive shape of generated stress pulse is a half-sine function, which is well suited for testing brittle materials and soft rubber-like materials in order to reach a rather constant strain rate. Meanwhile, for the tests of metals, a pulse shaper can be used to reach a rather classical trapezoidal pulse similar to that of the classical pressure bar tests. Furthermore, it is also possible to modify the stress pulse by shaping the discharge current using a specially designed active coil array and a sequential switch.

Finally, a number of different materials were tested in compression and tension using this electromagnetic split Hopkinson bar system. The same materials were also tested using the traditional split Hopkinson bars. It turns out that the results obtained by the present device are consistent with those by the traditional split Hopkinson bars.

Compared with traditional pulse generation techniques by the impact of a projectile or by a sudden release of a pre-stressed section, the proposed electromagnetic energy conversion technique can be accurately triggered within several microseconds. It is, therefore, a good candidate to supply the symmetrical and synchronous loads in bidirectional or biaxial split Hopkinson bar systems in the future.

1. Introduction

Split Hopkinson pressure bar (SHPB) [1] is a widely used experimental technique to characterize the mechanical properties of materials at high strain rates. The original compressive version developed by Kolsky [2] in 1949 places a thin specimen disc between incident and transmission bars. With the impact of a so-called striker bar, a compressive stress pulse is generated in the incident bar. This incident pulse will load the specimen disc and generate reflected and transmitted pulses. Recording of these three pulses will allow for the measurement of stresses and particle velocities at specimen/pressure bar interfaces leading to an average nominal stress–strain relation [3]. Split Hopkinson bar techniques have also been adapted to torsional [4, 5] and tensile [6–8] loadings.

In the SHPB system, the loading is an incident stress pulse (compressive, tensile or torsional pulse), which is created by two basic methods. One is to impact the incident bar by a projectile (striker bar or tube in the tensile version [7]). The projectile can be launched by explosive, gas gun, or more recently, by electromagnetic driving technology [9, 10]. Another method is the sudden release of a pre-stressed section of the incident bar with torsional [5], tensile [8], or even compressive elastic strain energy [11]. The desired loading pulse has generally a trapezoidal shape. Its amplitude can be controlled by the impact velocity of the projectile or the stress level in the pre-stressed section, and the pulse length depends on the round trip duration of the elastic wave inside the projectile or the pre-stressed section.

The aforementioned techniques to generate the incident pulse are basically triggered by mechanical means, which creates a difficulty to control the triggering instant within an accuracy of a millisecond. Compared with the entire pulse length of about hundreds of microseconds of a common SHPB system, it is hardly possible to launch simultaneously multiple incident pulses to realize a combined tension-

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torsion test or a bi-axial impact test. In order to obtain an accurate trigger control, an alternative technique to generate the stress pulse is highly desired.

For this purpose, this paper proposes an original electromagnetic method to create directly the incident pulse in the incident bar. Indeed, the method of electromagnetic energy pulse conversion to stress pulse has been studied for decades, mainly in the development of electromagnetic riveting techniques [12–14]. Such a technique uses a copper pancake coil connected with a capacitor array to form an LC circuit and a copper driver plate. An appropriate rapid discharge current can be obtained. When it flows through the copper pancake coil, a high magnetic field is generated around it, which creates an induced current in the coupled copper driver plate. Thus, an eddy-current magnetic field is created by the action of the high magnetic field, and it will generate a repulsive force pulse. This eddy force pulse will propagate through an amplifier and generate a stress pulse in the rivet. That is why the electromagnetic riveting is also called stress-pulse-riveting[13].

In this paper, the principle of electromagnetic riveting is adapted to create directly an incident pulse in the split Hopkinson compression/tension bar without mechanical commands. The principle and implementation of this new apparatus, called the electromagnetic split Hopkinson pressure bar, will be introduced in detail in Section 2 of this paper. The control of the generated incident pulse shape is explained in Section 3. Finally, four different types of materials (epoxy, 2024 Al-alloy, copper, and PMMA) are tested employing this new apparatus at high strain rates in compression, while two kinds of materials (2024 Al-alloy and copper) are tested in tension. The results are in good agreement with those obtained with a traditional split Hopkinson bar device.

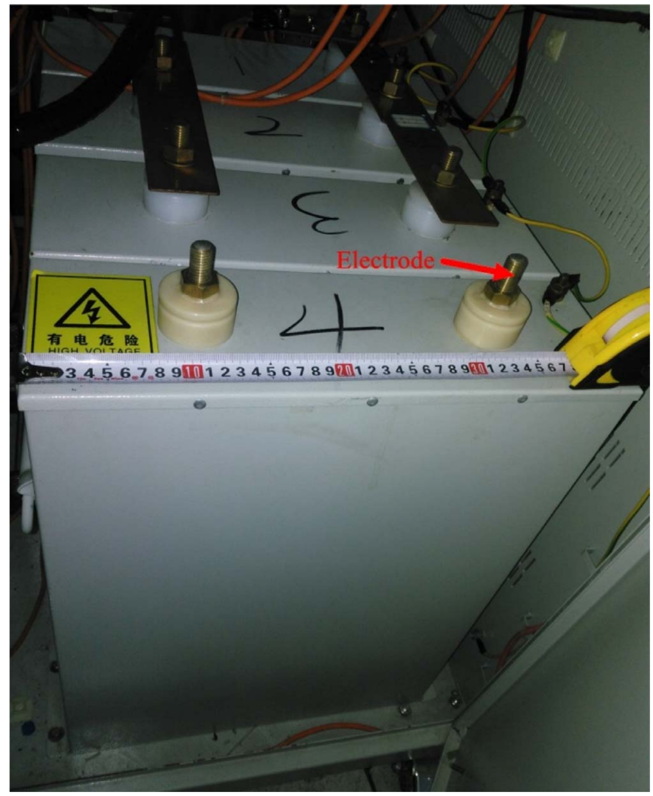

Fig. 2. A photograph of the capacitor group.

2. Electromagnetic split Hopkinson pressure bar setup

The proposed electromagnetic split Hopkinson pressure bar setup is composed of charging and LC discharge circuits, a stress pulse generator containing active and inductive coils, and a common pressure bar system. A schematic diagram of the setup is shown in Fig. 1.

2.1. Charging and LC discharge circuit

The charging circuit includes a high-power transformer and a bridge rectifier, which can convert the industrial AC voltage to the preset high DC voltage. A group of the four customized pulse capacitors (Fig. 2) is

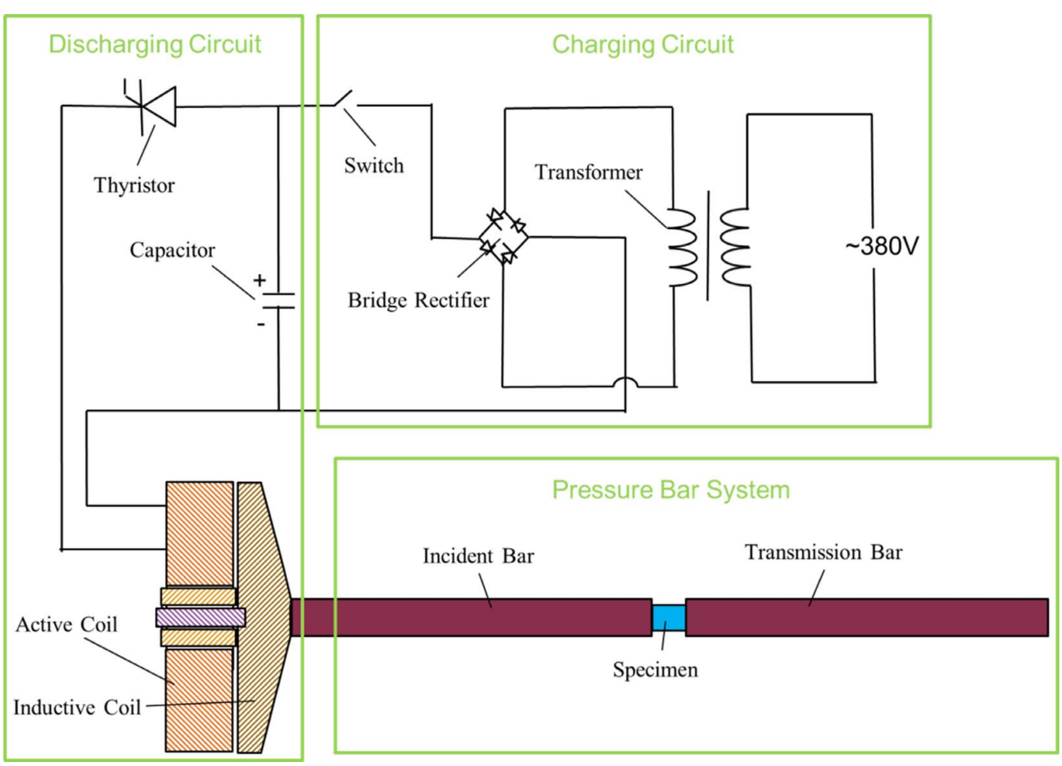

Fig. 1. The schematic diagram of the Electromagnetic SHPB setup.

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