Chapter 11
An Optimization-Based Approach to Design a Complex Loading Pattern Using a Modified Split Hopkinson Pressure Bar

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11.1 Introduction

The split Hopkinson pressure bar (SHPB) technique is used to characterize the mechanical response of a material during impact loading when a single stress wave pulse passes through that material [1]. The SHPB setup consists of two long bars: an incident bar and a transmission bar. The specimen, which needs to be characterized, is placed between these two bars. A striker propelled from a gas gun hits the incident bar generating a stress wave that propagates through the incident bar. A part of this wave is transmitted to the specimen and the transmission bar while the remaining part of the wave reflects back into the incident bar. By measuring the incident, transmitted, and reflected waves, the mechanical properties of the specimen are determined for high-strain-rate deformations.

Additionally, SHPB can be used as an actuator to generate impact loading. Sarntinoranont et al. [2] proposed the use of SHBP in generating an impulsive overpressure loading to study the effect of sudden over-pressurization on a brain tissue. This loading technique was used to investigate the tissue injury mechanism that causes blast-induced traumatic brain injury (bTBI). However, the pressure loading experienced by the brain tissue due to a blast exposure is extremely complex and highly dynamic, which cannot be approximated as a single overpressure pulse [3]. Thus, the traditional SHPB technique cannot be used to replicate this complex loading profile.

Our study presents a novel approach to design an actuator based on the SHPB, which can ultimately be used to generate highly dynamic loading profiles. The principal idea here is to build the incident bar by joining multiple rods, made up of different materials, to increase the dynamic nature of the incident pulse. When a stress wave propagates through this multi-material incident bar, the difference in the elastic properties of the materials on either side of the interface where two rods are coupled creates an impedance mismatch for wave propagation. Due to the impedance mismatch, part of the wave transmits into the next rod, while the other part reflects back. This transmission and reflection repeat at every intermediate interface, which generates a complex stress wave at the other end of the bar because of the wave interference. With this understanding, SHPB can be used to generate a desired complex loading profile by simply modifying the incident bar.

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11.2 Methods

The parameters affecting the modified SHPB actuator design are the length and material selection of the rod components that make up the incident bar. These design parameters determine the stress wave profile generated by the modified SHPB actuator. Based on the desired loading profile, the parameters need to be optimized such that the loading generated by the actuator is same as the desired loading profile. This optimization is achieved by coupling the finite element analysis of the modified SHPB with an optimization algorithm.

A finite element (FE) code in MATLAB (MathWorks Inc, Natick, MA, USA) was developed to simulate the modified SHPB. The FE simulation was performed by solving a one-dimensional wave equation for an elastic medium using the method of characteristics [4]. An optimization algorithm, Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) [5], is used to minimize the Root-Mean-Square Error (RMSE) between desired loading and the loading generated by the actuator. This RMSE is computed in the frequency domain instead of the time domain to emphasize the dynamic nature of the loading patterns. Firstly, NSGA-II initializes the optimization process by generating a random set of parameter values. RSME is then computed for these new random designs using finite element simulations. Based on the performance of these designs, NSGA-II further modifies the parameters to create new designs that are yet again evaluated by computing the RMSE. This process is iterated until optimal parameters are determined, which eventually minimize the error between desired loading profile and the loading profile obtained by the modified SHPB actuator.

11.3 Results

To test the methodology proposed above, an optimization problem is established. For this test problem, pressure loading that was based on the brain tissue's response to a blast wave [3] was chosen as the desired loading profile. The incident bar was simulated as a multi-material bar made by joining 10 different rod components. Figure 11.1 shows the comparison between desired loading profile and the loading profile generated by the optimized SHPB actuator.

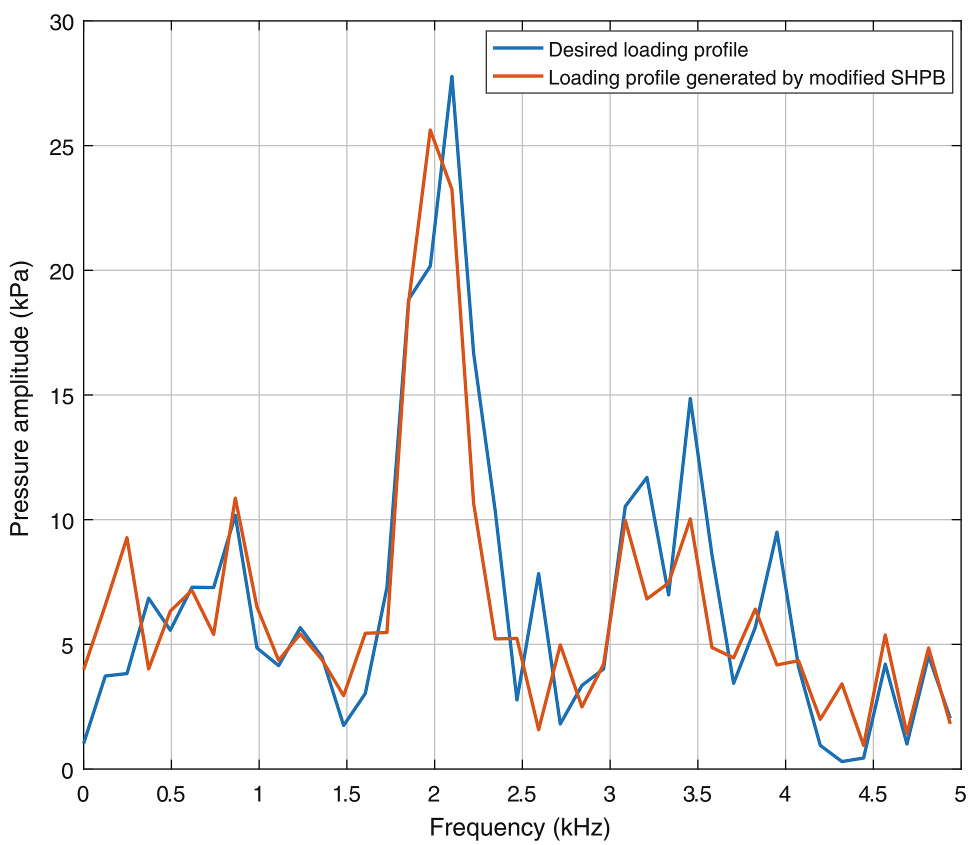

Fig. 11.1 Comparison of loading profiles in frequency domain

The error between these loading profiles can be reduced further by increasing the number of individual rod components used to build the multi-material incident bar. However, such reduction in error increases the total length of the modified SHPB setup, which is usually a limiting aspect of the experimental setup.

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