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Proceedings of the Munich Symposium on Lightweight Design 2020

Tagungsband zum Münchner Leichtbauseminar 2020

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Preface

Dear reader,

the Munich area is an important center of lightweight design: it hosts major industries, including aerospace or automotive, several renowned universities and research centers. It has been an epicenter of innovation and academic research for decades. In 2003, the Technical University of Munich, the Universität der Bundeswehr, and the University of Applied Sciences in Munich initiated the first symposium on lightweight design to promote the local networks of industry and academia. Over the years, this has turned into a national platform for the exchange of ideas and research activities. Experienced and young professionals from both, industry and academia, present their recent work at the Munich Lightweight Symposium. Summaries of most talks are now available for the first time as Proceedings (Tagungsband zum Münchner Leichtbauseminar 2020) as an online book by Springer. We are pleased to present our conference now to a larger audience and hope you enjoy it.

Best regards

January 2021

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Organization

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Design of a motorcycle triple clamp optimised for stiffness and damping

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Abstract. Engineers have always faced the challenge of solving conflicting objectives such as high stiffness combined with high damping. Structurally optimised components are used, especially by pushing lightweight construction. This design adaptation of component mass and stiffness generally has a negative effect on the dynamic component properties, as both the natural frequencies are shifted and component damping is reduced. In the majority of applications, the resulting vibrations are undesirable and must be reduced by suitable mechanisms. For example, vibrations in the vehicle can lead to a reduction in driving comfort or to a reduced service life.

One approach to solving conflicting objectives is the targeted integration of effects into components through additive manufacturing. In this paper, the effect-engineering on a laser beam melted motorcycle triple clamp is illustrated. The triple clamp is a highly dynamically loaded structural component where unwanted vibrations occur due to road unevenness, leading to critical hand-arm vibrations. This paper focuses on the simulative design of the triple clamp. The triple clamp is topology-optimised and extended by the effect of particle damping, so that the component is optimised in terms of stiffness, damping and mass. The optimisation also makes it possible to achieve a high degree of functional integration by saving 20 components. The effect of particle damping is experimentally evaluated by preliminary studies, which show that component damping can be increased by up to a factor of 20. The laser powder bed fusion (LPBF) makes it possible to store unmelted powder in the interior of the component in a targeted manner and thus produce particle-damped structures inside the triple clamp.

Keywords: Laser powder bed fusion (LPBF), Particle damping, Additive manufacturing (AM), Functional integration, Design for additive manufacturing (DfAM), Effect-engineering

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1 Introduction

In recent years, the design for additive manufacturing (DFAM) has been supplemented and improved by more and more methods to design and manufacture even more efficient products [1–6]. In the field of DFAM, the design of assemblies offers great potential [7,8]. Any optimisation of existing individual parts cannot be as good as rethinking the entire assembly design [7,8]. One obstacle in the design of assemblies is the restriction of the design space due to design limitations. These design limitations can occur at points where two or more areas with conflicting design specifications meet, for example high stiffness and high damping [9]. Thus, the question arises how these limits can be overcome and shifted in order to develop more efficient products and to raise potentials.

The laser powder bed fusion (LPBF) has so far been characterised by its ability to produce stiffness-optimised components with a minimum of material. Recently, it has also become possible with this production method to integrate damping elements locally in vibration-prone areas [10–21]. For this purpose, unmelted powder is left inside the component. In keeping with the "Complexity for free" [22] principle, "Damping for free" applies to additively manufactured components, since neither mass nor costs increase with increasing damping compared to the additively manufactured reference component [21]. Here, a reduction in vibration by a factor of more than 20 can be achieved from a few Hz up to several kHz. Thus, the LPBF makes it possible to solve the conflict of objectives between high stiffness and high damping.

In this paper a method for the design of effect optimised components with regard to stiffness and damping is presented. The effect of particle damping is evaluated on laser beam melted bending beams made of AlSi10Mg. These results are then transferred to a motorcycle triple clamp as a demonstrator. Here the assembly of the triple clamp is considered in order to realise a high degree of functional integration. The motorcycle triple clamp is designed and optimised for the conflicting objectives of stiffness, mass and damping. The stiffness of the triple clamp is one of the criteria for riding safety [23]. At the same time, critical hand-arm vibrations must be reduced so as not to impair driving comfort and health [24]. The damping elements previously used in triple clamps reduce stiffness and thus driving safety. The triple clamp is simulatively optimised with regard to stiffness by carrying out a topology optimisation. Subsequently, particle-filled cavities are integrated into the component, thus integrating the effect of damping. The effect of the particle damping is estimated for the motorcycle triple clamp from the damping curves of the parameter study.

2 Theoretical background

2.1 Hand-arm vibrations

Excessive vibration in the hand-arm area can not only reduce comfort, but can also lead to illnesses over a longer period of time, which are also known as Hand-arm vibration syndrome (HAVS) [24–27]. HAVS can lead to vascular, neurological and muscularskeletal disorders [24–26]. These disorders are recognised throughout Europe as occupational diseases [26].

Vascular disorders are characterised by pale or white fingers, especially in cold weather [24,26,28]. This disorder, known as Raynaud's phenomenon, is due to a temporary interruption of the blood supply to the fingers [24,26,28]. The sense of touch can be impaired or completely lost [24,26]. In addition, finger mobility is restricted. In general, the risk of accidents when handling machines is increased [26]. The Raynaudian phenomenon occurs in northern countries with colder climates in about 80-100 % of the workers exposed to high exposure levels at work [28]. Even in the general male population, this value is between 1.5 and 14 % [28]. The effects of the vascular disturbances depend on the amplitude, frequency, direction, impact and duration of the vibration exposure [26].

If exposure to vibration occurs over a long period of time, vascular symptoms may worsen and neurological disorders such as carpal tunnel syndrome (CTS) may also occur. [26]. The effects on healing are lower in neurological diseases than in vascular disorders [28].

Prolonged vibration stress can also lead to muscular diseases such as pain in the hand-arm area and a reduction in muscle/gripping strength and to arthritis or tendinitis [24,26]. Fig. 1 schematically shows the occurring consequences of HAV.

ISO 5349-1 can be used for the calculation and assessment of vibration exposure [26]. According to EU Directive 2002/44/EC, measures must be taken to reduce vibrations for workers from a daily exposure limit value of 2.5 m/s^2, related to 8 hours. The maximum permissible daily exposure action value is 5 m/s^2. Persons exposed to an acceleration of 2 m/s^2 for less than 8 hours can be expected to suffer minor hand-arm disorders. [26].

One of the first studies on hand-arm vibrations of motorbikes was conducted in 1997 among police motorcyclists [24,29]. It was found that finger numbness, finger stiffness and shoulder pain are common [24,29]. In addition, in everyday driving situations from approx. 2 hours of driving time, it is to be expected that the exposure to vibrations is higher than specified in international guidelines [30–32]. Further measures to reduce vibrations must therefore be considered. Vibrations on the motorcycle can be caused by the engine, by unfavourable mass moments of inertia, imbalances or by external forces such as road unevenness [23,32,33].

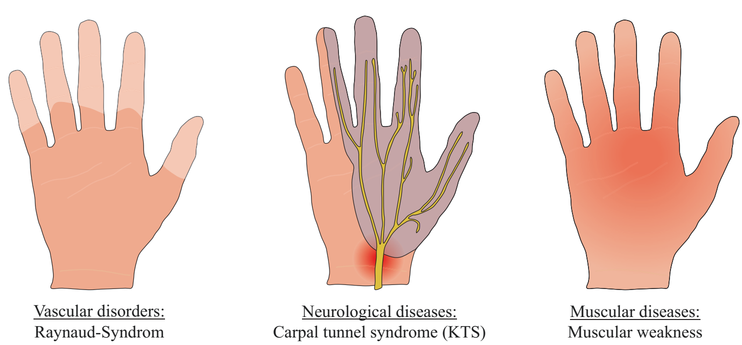

Fig. 1. Possible diseases caused by hand-arm vibrations (HAV)

2.2 Measures to reduce hand-arm vibrations on motorcycles

In the following, measures are presented for motorcycles to reduce vibrations caused by road unevenness and engine vibrations.

In order to reduce vibrations caused by uneven road surfaces, tyres play a central role due to their suspension and damping properties [23]. In addition, spring and damper elements are integrated in the stem so that the wheel can follow the uneven road profile in a vertical direction, but the motorcycle and rider do not make any vertical movements [23]. In order to optimally adjust the damping properties in the stem, semi-active or in rare cases also active damping systems are used [23]. As a rule, you can choose between different driving modes, which can be set to either comfort (high damping), sport (high driving safety combined with low damping) or a compromise of both [23]. Thus, there is always a conflict of objectives between driving comfort and driving safety. [23]

Rubber elements for engine mounting in the frame or an elastic decoupling of the handlebars from the frame help to reduce the transmission of engine vibrations to the hands [23]. It is important to note that the connection between the engine and the frame must be as rigid as possible in order to achieve sufficient driving safety. Thus there is a conflict of aims between stiffness and damping [23]. Particularly in the case of sports motorcycles, vibrations with the associated loss of comfort are accepted in order to achieve a high level of driving safety [23].

This raises the question of how high damping can be achieved at the same time as high stiffness in motorcycles, while keeping the mass low. One solution is, for example, the integration of particle damping in the handlebars [34].

2.3 Use of laser beam melted particle dampers

Laser Powder Bed Fusion (LPBF) is a manufacturing process in which the component is built up layer by layer by local melting of powder [2,35]. Furthermore, with LPBF it is possible to leave unmelted powder inside the component and thus integrate the particle damping effect into the component [16,19]. Through the combined forces of inelastic impacts and friction, either particle/particle or particle/wall interaction, kinetic energy is absorbed from the vibrating main structure resulting in increased damping [36,37]. A simplified diagram of a particle damper is shown on the left side in Fig. 2. On the right side in Fig. 2 the effect of particle damping is shown qualitatively related to the initial situation without particle damping. A clear drop in amplitude can be seen in the frequency transfer function (FRF) of the particle damped curve. This amplitude reduction is also effective over a wide frequency range from a few Hz to high-frequency applications up to several kHz [21,36,38–40]. This applies both to cold and cryogenic applications [41] and to warm temperatures of up to 2000 °C or more [37,42]. In addition, the particle dampers can be designed so that they hardly affect the stiffness and mass [10,37,43]. Another advantage is that this is a passive measure that does not require additional energy [36,37].

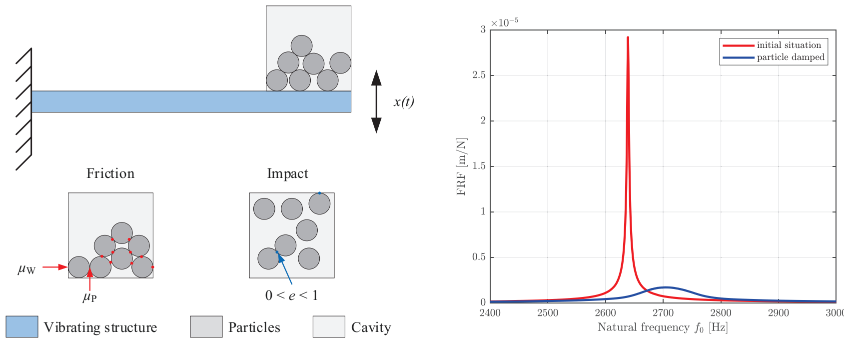

Fig. 2. Schematic diagram of a particle damper [21]

3 Design of a motorcycle triple clamp

In order to reduce critical hand-arm vibrations on the motorcycle, a motorcycle triple clamp is designed in this chapter under the aspects of high stiffness and high damping with low mass at the same time. In the first step a method for the design of stiffness and damping optimised components is presented. Afterwards the effect of particle damping is quantified by a parameter study. Based on this, the loads at the triple clamp are identified and the developed method is applied to the motorcycle triple clamp. For this purpose, the stiffness to weight ratio of the triple clamp is optimised by means of a topology optimisation. Subsequently, cavities for particle damping are integrated in the vibration-prone areas of the triple clamp, which are identified from a modal analysis. Finally, a static simulation is carried out to verify the mechanical strength.

3.1 Methological approach

The procedure for designing a stiffness and damping optimised component is shown in the form of a flow chart in Fig. 3 and is described in detail below. In order to solve conflicts of objectives during component design with regard to high stiffness combined with high damping, particle damping must be selected as a suitable measure. For example, the particles can be integrated in the area of the neutral fibre, thus enabling a component design optimised in terms of stiffness and damping.

Subsequently, the critical mode shapes, natural frequencies and occurring forces must be identified and calculated, since the effect of particle damping is highly nonlinear [21,44,45] and is influenced by it. As there are usually no damping values for these boundary conditions, they must be quantified. For this purpose simulation methods like the Discrete Element Method (DEM) or experiments like a parameter study can be performed. For a parameter study the set-up has to be chosen in a way that the load cases (tension, compression, bending or superposition) correspond to those of the structural component to be optimised. By means of the parameter study, damping curves are determined as a function of different excitation forces, natural frequencies and cavity volumes, so that the damping of the structural component to be optimised can be estimated.