VIBRATION BEHAVIOUR OF FLAT AND SHOT PEEN FORMED METAL SHEETS BY USING OF DIFFERENT COUPLING CONDITIONS

Clausen R., Meding M., Garbers N.
University Hamburg, Germany

ABSTRACT

This paper presents details of a study about vibration behaviour of flat and shot peen formed metal sheets as a function of their coupling conditions. The results were obtained by using of system analysis, which deals with techniques for determining the inherent properties of a dynamical system. This can be done by stimulating the system with measurable forces and studying the response to force ratio.

The vibration measurements were carried out with different workpiece-couple systems. The metal sheet was fixed both by area-contact about the whole plate and by four-point-contact on whose corners. In case of point-contact for instance Belleville springs and metal rubber buffers were used as couple elements. Area-contact was realized among others by using of froth rubber mats and waterfilled rubber sacs with a certain liquid pressure. Based on the results of the experimental investigations some suitable couplings are proposed.

KEYWORDS

Peen Forming, Vibration Behaviour, Coupling Conditions, Deflection of Metal Sheet, Natural Frequencies, Damping, Compliance, Modal Shape

INTRODUCTION

In connection with shot peen forming the vibration behaviour of the fixed metal sheet has an important influence on the reproducibility of forming process and on the level of noise emission, which is generated during manufacturing. During impact of peen on metal sheet some cinetic energy going lost in consequence of peen recoil and initiation of workpiece vibrations in his natural frequencies. This unwanted vibrations are depending on the geometry of the metal sheet, the stiffness respectively compliance of the couple elements and the damping properties of the workpiece-couple system. The utilization of a maximum of available forming energy requires a minimum of compliance of the workpiece-couple system. For a good process reproducibility also high damping properties are advantageous.

In order to optimize the dynamic characteristics of the workpiece-couple system the vibration behaviour of flat and shot peen formed metal sheets has been investigated under different coupling conditions. At first it was to clear, how the modal parameters are influenced by the degree of deformation of a shot peen formed metal sheet. After then vibrations of different coupled flat metal sheets were analyzed in order to find suitable coupling solutions.

A complete description of the dynamic characteristics of a mechanical structure can be obtained by determining of the modal parameters, modal frequency, modal damping and modal shape. Additionally it is advantageous to determine the compliance, which describes, if a structure can be easely excitated or not. The experimental system analysis (1) were carried out on quadratic metal sheets with a lateral length of 280 ± 3 mm and a thickness of 5 ± 0,2 mm.

MODAL PARAMETERS OF A "FREE-LYING" SHOT PEEN FORMED METAL SHEET IN DEPENDENCE ON THE DEGREE OF DEFORMATION

In order to realize a "free-lying" coupling, the workpiece can be put on two tight elastic ropes. The natural frequency of such a couple system lies with 10 Hertz far away from the lowest natural frequency of the workpiece. Because the shot peen formed metal sheets possess the shape of a calotte the maximum deflection z_{max} were chosen as degree of deformation.

Table 1 contains the results of modal analysis of "free-lying" shot peen formed metal sheets with different maximum deflections in comparison to a flat metal sheet (workpiece number 1). Fig. 1 shows the node lines of the accessory modal shapes determined on a flat undeformed metal sheet. It can be seen that in case of small deflections up to z_{max} = 2,5 mm the natural frequencies practical don't change. All values are located within the tolerance for the natural frequencies up to seven per cent which is formed by the tolerances in size and thickness of the workpiece. When deflection increases clearly modal frequencies begin to change. In dependence on the modal shape natural frequencies increase or decrease visible.

Similar to the natural frequency compliance shows also very small changes at lower degrees of deformation. The values are also located within the tolerances of the measuring equipment. At higher deflected metal sheets compliance at the first modal shape increases very much. In consequence the dynamic stiffness of the structure is considerably reduced.

In contrast with natural frequency modal damping of the first modal shape begins to change already at light deflections. The damping increases up to 1,1 per cent what means a absolute increasing of the damping effect about a third. In case of higher deformed metal sheets modal damping decreases clearly. So it can be concluded that a high degree of deformation reduces the damping effect of the structure. At higher modal shapes changes in damping are visible smaller.

number of workpiece	1	2	3	4	5	6
max. deflection z_{max} [mm]	0	1,0	2,2	6,7	9,5	13,5
modal shape	1	1	1	1	1	1
modal frequency [Hz]	208	208	209	189	172	177
modal damping %	2,4	3,5	3,4	1,1	1,1	1,1
max. compliance [µm/N]	46	38	37	136	186	178
modal shape	2	2	2	2	2	2
modal frequency [Hz]	389	384	395	501	594	731
modal damping %	1,4	1,5	1,7	0,4	0,6	1,4
max. compliance [µm/N]	22	23	20	75	24	10
modal shape	3	3	3	3	4	4
modal frequency [Hz]	540	535	536	527	502	579
modal damping %	1,2	1,0	1,0	0,4	0,4	0,5
max. compliance [µm/N]	22	26	26	65	45	35
modal shape					5	5
modal frequency [Hz]					515	506
modal damping %					0,4	0,4
max. compliance [µm/N]					62	38

Table 1: Results of modal analysis of different deflected shot peen formed metal sheets

Experiments presented that modal frequencies and modal shapes of flat and not many deformed metal sheets don't vary significantly. In case of modal damping could be determined that a light deformation of a quadratic metal sheet improve whose damping ability. In this connection must be considered that the maximum spherical deflection is a function of the workpiece size and the parameters of the shot peen forming process (2).

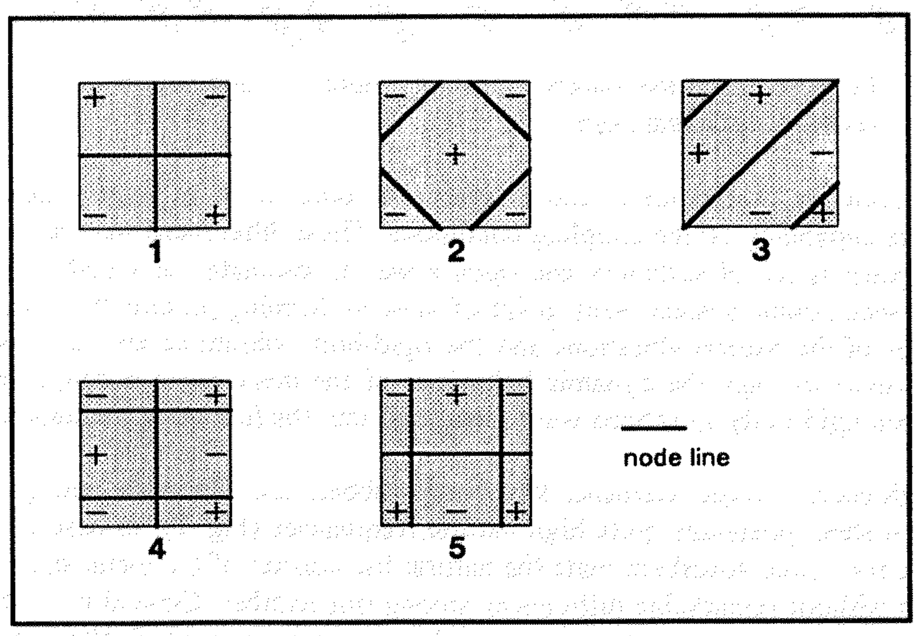

Fig. 1: Node lines of modal shapes of a flat metal sheet. The numbers correlate with the number of modal shapes in Table 1.

VARIATION OF MODAL PARAMETERS OF A FLAT METAL SHEET BY USING OF DIFFERENT COUPLING CONDITIONS

In order to eliminate influences by the shape and size of the workpiece, system analysis were performed with a flat metal sheet by using of following coupling conditions:

- four-point-fixing with bump rubbers (point-contact)
- four-point-fixing with Belleville springs (point-contact)
- four-point-fixing with metal rubber buffers (point-contact)
- put on two elastic ropes (point-contact)
- stick on a bitumen-impregnated mat (area-contact)
- put on a mineral wool mat (area-contact)
- put on a sound absorbant mat for track beds (area-contact)
- stick on a sound absorbant mat for vehicles (area-contact)
- stick on a froth rubber mat (area-contact)
- put on a waterfilled rubber sac (area-contact)

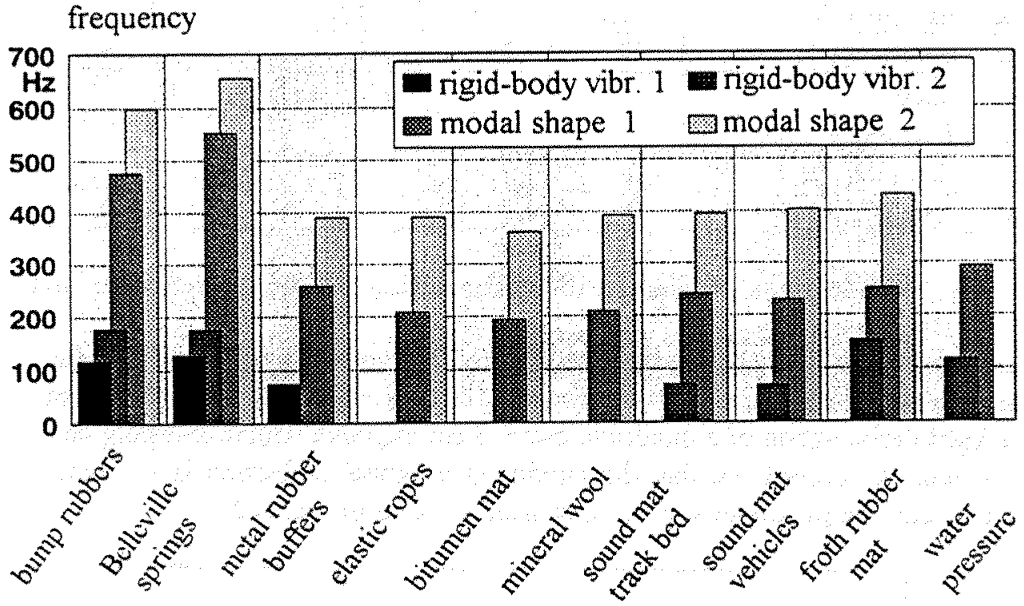

Fig. 2: Frequencies of the lowest rigid-body vibrations and natural vibrations of a different coupled flat metal sheet

During excitation of the metal sheet significant differences of impact noise were already registred in depending on the coupling conditions. These differences were almost located in the higherfrequent range of audibility and open a way to estimate the specific sound emission of the workpiece-couple system. With point of view on forming process the lowerfrequent signal frequencies of the natural vibrations and the rigid-body vibrations are very important because these influence strongly the dynamic behaviour of the metal sheet during forming. Therefore the first two rigid-body vibrations were integrated into the following evaluation.

When high-elastic couple elements like bump rubbers and Belleville springs were used, the fixed metal sheet possesses quite high natural frequencies (Fig. 2). In case of stiff couple mediums like the sound absorbant mats the natural frequencies of the metal sheet are significantly lower and without remarkable differences among one another. General it can be said that high natural frequencies are advantageous in order to get only small displacements of the metal sheet during forming process and with that a good reproducibility. This requirement is most satisfied by high-elastic couple elements and approximately by using of froth rubber mat and water pressure coupling.

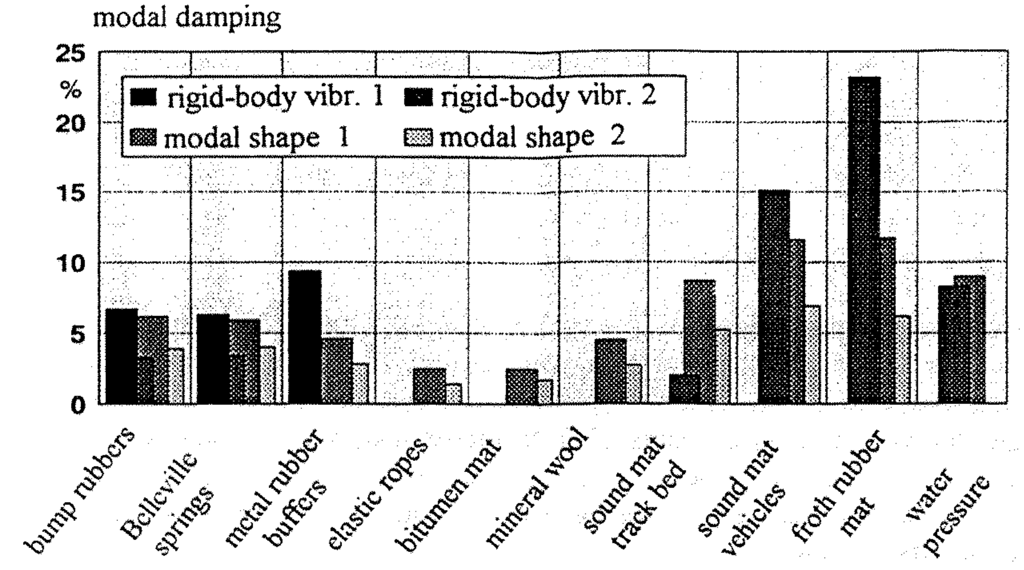

Fig. 3: Modal damping of the lowest rigid-body vibrations and natural vibrations of a different coupled flat metal sheet

The second important requirement in direction of a high damping is most satisfied by using of froth rubber mat, water pressure coupling and approximately by metal rubber buffers. Fig. 3 shows that the modal damping of a sound absorbant mat for vehicles is something higher than in case of water pressure coupling but in contrast to this the compliance of the first rigid-body frequency is unfavourable high (Fig. 4). The using of bump rubbers and metal rubber buffers leads also to respectable modal dampings of the workpiece-couple system especially in the range of the lower rigid-body vibrations. In case of Belleville springs damping properties are also quite good but the compliance at the first rigid-body vibration shows constantly a unfavourable high value (Fig. 4). In order to get a good reproducibility during shot peen forming the most important modal characteristic is embodied by the compliance. Fig. 4 presents that the best results were obtained by area-contact of the metal sheet with a waterfilled rubber sac or froth rubber mat.

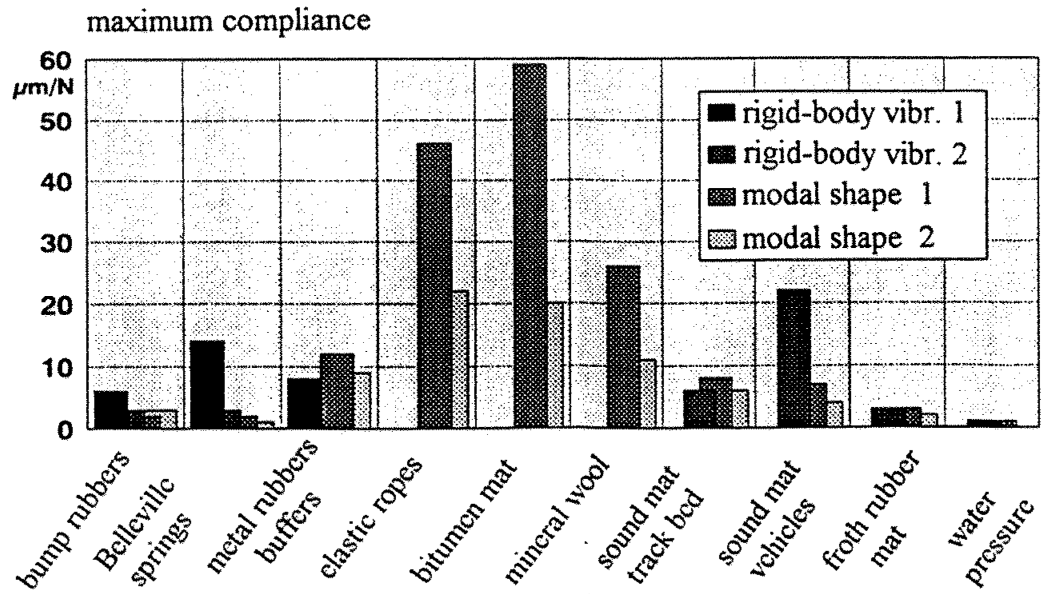

Fig. 4: Maximum compliance at the lowest rigid-body vibrations and natural vibrations of a different coupled flat metal sheet

CONCLUSIONS

A summary of the modal parameters of different shot peen formed metal sheets is presented in Table 1. These results give a specification of the modal characteristics of metal sheets in dependence on his maximum deflection. It was found that there was no significant difference between the vibration behaviour of flat and not many deformed metal sheets. In this cases modal frequencies and modal shapes are quite similar. Only when the deformation degree is higher a change of the modal parameters is detectable.

The demanded high damping of a workpiece-couple system can be realized both by using of area-contact and in two cases by four-point-contact. It can be concluded that water pressure coupling seems to be the best workpiece-couple system. Also suitable modal characteristics supplies the area contact by using of froth rubber mat, which is sticked on the metal sheet. Simple realization and good allround-properties like quite low compliance, good damping and high natural frequencies can be reached by four-point contact with the help of bump rubbers and metal rubber buffers .

REFERENCES

1. Bruder M.: Beitrag zur Vorherbestimmung der Blechverformung beim Umformstrahlen mit gezieltem Kugelbeschuß. Dissertation TU Hamburg-Harburg, 1992

2. Clausen, R.; Bruder M.; Garbers, N.: Grundlegende Untersuchungen des Verformungs- und Schwingungsverhaltens von Blechbauteilen beim Umformstrahlen mit gezieltem Kugelbeschuß. Teil II, Abschlußbericht Volkswagen-Stiftung, 1992