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Dynamics Modeling and Optimization of a Wrapper Flow Pack Mechanism

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Abstract: This paper is about a mechanical solution to vibration problem of a wrapper flow pack mechanism, which is used in packaging industry. The target mechanism is the welding head of the machine where the vibration is generated, due to eccentric masses rotating with a cut-on-the-fly motion law. Consequently, production rate is limited by the vibration at 200 pieces per minute. To reduce the vibration so that the production rate can exceed over 200 ppm, two ways of improvements are considered. The first one is optimizing the motion law. The other one consists in mechanical modifications which eliminates or balance out the inertia forces derived from the eccentric rotating mass. This research implements the second way of adding balance weights and discusses the properties of it. During analysis, the software ADAMS which provides kinematic simulation is used as the analytical tool to test and examine the solutions proposed.

Index Terms: Flow pack mechanism, Multi body simulation, Packaging machines, Vibration.

I. INTRODUCTION

This project addresses a problem related to the increase in productivity of a packaging machine of type flow pack, a term that indicates machines of continuous type, with horizontal flow of product that is inserted in a tubular plastic film [1], [2] as shown in Fig. 1. This kind of machinery is largely used in food industry [3] and its optimization through simple and inexpensive solutions is of great interest for mass production lines of packaging [4], [5]. The main obstacle to the increase of productivity is given by the motion of the welding head, which is not uniform, with acceleration and deceleration to return to the starting point of the cycle after the phase of welding and cutting. Suffering from the sudden change in value of the acceleration, great displacement and vibrations take place because of the non-balanced inertia forces on the head [6]. To decrease the vibration, two ways are considered feasible.

The first one is modification of the motion law from the motor [7]. The second way is to modify the mechanical structure such as redesign the mechanism or adding a balance weight [8], [9]. In this work, a modification realized by adding balance weights will be discussed, through the software ADAMS which allows one to simulate the kinematic and dynamic movement and reaction of both the system and each component [10]. After a brief introduction of packaging machines, the welding head of the project with its various components and features is discussed, beside the schematic and nomenclature used during discussion, the current performance and the goal.

The subsequent paragraphs are devoted to the modeling of the machine and simulation of the motion in ADAMS environment. By building up the simplified models [11] of the original structure of the machine and the modified ones in ADAMS, not only the effectiveness of different solutions is obtained, but it is possible to discuss them and to compare them by each other's [12]. The conclusion about benefit obtained by adding balance weight is verified and the best solution for the practical machine prototype is confirmed. Finally, a description of the final mechanic solution of adding balance weights to the original machine is presented.

II. THE WELDING HEAD

The mechanism that performs the welding and cutting of the packages has several transverse elements and is rather complicated. To facilitate the understanding, the construction of the welding head has been resented in CAD software and, subsequently, the pattern of operation of the mechanism with the nomenclature will be used in the rest of the discussion.

Fig. 2 and 3 show the main parts (to avoid the intersection of multiple arrows, each part is indicated only once):

1. support plates connected to the rest of the frame and which are also the seats for the bearings of the wheels and the shaft that moves the mechanism (4,5,6) and the horizontal rails for trolleys-lance (13). They are connected to the rest of the frame with the structure which also has the task to ground the stresses produced by the same mechanism;
2. brushless motor;
3. right-angle gearhead;
4. driving shaft of the mechanism;
5. lower wheels which engage the wheels of the motor shaft and that move through the supports (11) the rods (12) and the upper crossbar (15). The rotational joint that connects the wheel to the supports is eccentric with eccentricity that can be of 33.5 mm, 52 mm or 74.5 mm. Each wheel has holes for each of the three with configurations, designed to make the machine more flexible to vary the length of the packages to be produced;

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6. upper wheels which engage the lower wheels have the same diameter of theirs (they are, consequently, homokinetic) and move the lower crossbar, connected through revolute pairs eccentrically and for which the same considerations made for the lower wheels;

7. lower crossbar, which is connected to the upper wheels, has holes that serve as guides for the four vertical rods (12). As result, the coupling between the lower crossbar

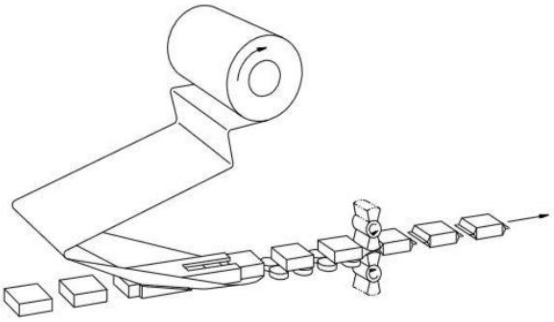

Fig. 1: Machine for winding continuous type flowrap

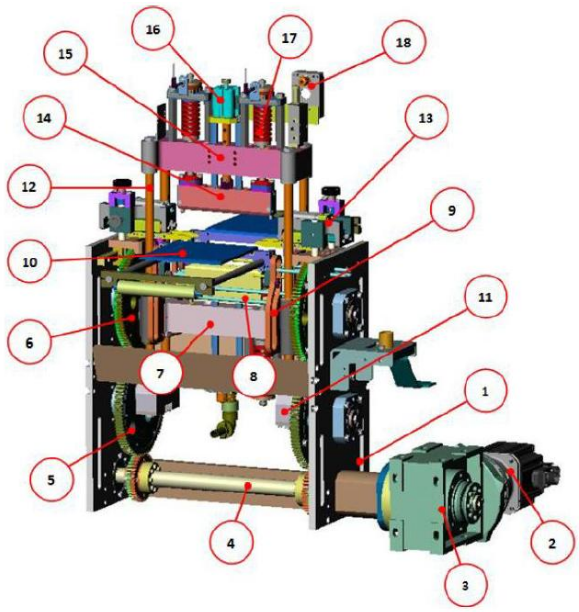

Fig. 2: CAD model of the welding head

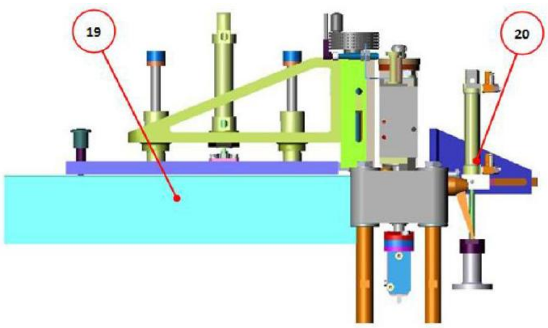

Fig. 3: Detail of the upper crossbar fitted with pressure and counterpressure

and rods prevents both the rotations of each other's, keeping the axes of the rods are always perpendicular to the axis of rotation of the wheels; in addition to, this the lower beam acts as a support for the lower jaw (8);

8. lower jaw is the name with which is often referred to the lower welding bar and which will be often used in the course of the treatment. As mentioned in the previous description of the motion of the bars, during the phase of circular trajectory the vertical displacement of the jaw is prevented by the preload given to the springs (17). When the jaws come into contact, they slide vertically with respect to the stringers and go to compress the springs, generating the pressure welding. It has a horizontal ribbing;

9. cams for opening the tape rigidly connected to the lower crossbar. Their profile is designed in such a way that, following the motion of the crossbar, the sliding of the pins connected to the belts (10) leads to the opening of these during the welding phase;

10. conveyor belts with pivots that slide inside the cam (9) and have the ability to open to make room for contact between the jaws and then close while welding so as not to drop or move the package;

11. supports for the rods, connected to the lower wheels as mentioned in (5);

12. rods;

13. carriers constrained to slide on a horizontal guide and move along with the rods (there is then a vertical relative motion without friction thanks to the wheels connected to the carriers). Their function is to bring the small lance, moved by a pneumatic drive, which have the task of carrying the bellows on the packs;

14. upper jaw. For them are valid the same considerations made for (8), with the difference that within there is a knife driven by the pneumatic piston (16) upon completion of the weld;

15. upper beam that, in addition to the functions performed by the lower one, constitutes a support for the elements (16) and (18) and has holes for fastening of tamper (19) and counter-presser (20);

16. pneumatic piston for actuating the knife;

17. springs preloaded to prevent the relative vertical motion of the jaws with respect to the cross members and generate during the phase of interference pressure for the welding phase;

18. electrical junction box for the heating circuits of the jaws and the drive (16), (19) and (20);

19. presser connected to the upper beam through bracket and consists of a pneumatic piston and a parallelepiped of sponge that, shortly after the end of the welding phase, is actuated to press the package, letting out excess air before the beginning of the second welding;

20. counter-tamper (optional), also fixed to the upper beam with a bracket and consists of a piston actuated shortly after the presser, which has the purpose to hold the product in position, preventing the flow of return air, caused by the same pusher. It moves with respect to the ordered position desired (for example can be used to ensure that a stack of handkerchiefs or wipes remains orderly).

Neglecting the interaction between the cams and the conveyor (which gives rise to two equal and opposite forces and of low intensity), the parts of the head described in the preceding paragraph that are involved in the motion are shown schematically in Fig. 4.

The mechanism can be considered on a plane, with only one degree of freedom identified by the angle between the position of the eccentric rotational joint of the lower wheel and the origin, which is considered the center of the spot welds. In the course of the discussion, especially in the case of the analysis of the data of the various tests, it is set equals to zero in the diametrically opposite point (the maximum distance between the jaws). For clarity: when the eccentric revolute pairs are more far

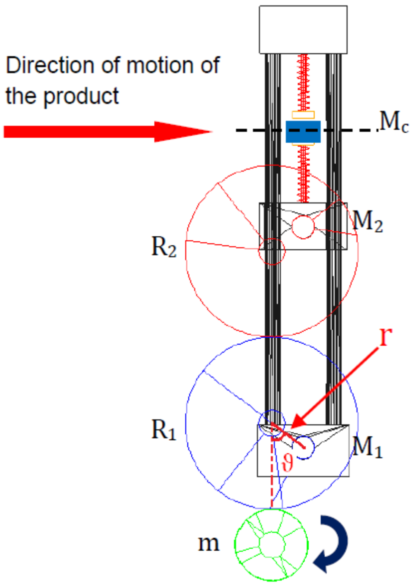

Fig. 4: Cam Roller Connections

from each other, the two welding jaws (also the crossbars which carrying them) are at the point of greatest closeness and, consequently, the jaws are in the point of maximum interference (and therefore, half of the stretch of welding); vice versa, when rotate half a turn, revolute pairs are at the point of maximum closeness, which coincides with the point of maximum distance between the two crossbars.

III. DISCUSSION OF POSSIBLE SOLUTIONS

It is not the purpose for this project of abandoning the existing machine and inventing a new mechanism which has less vibration, but to improve the performance of the machine by limiting the vibration caused by rotational eccentric mass and its inconsistent motion law.

In Fig. 5 is the welding head, the mechanism to be studied, represented in CAD software. As one can see, the structure is already compact and has already applied on the prototype machine. It is required to maintain as small as possible the necessity to change any component in the machine and, moreover, a bulky external device added on the welding head is not welcome because of the constraint of limited space in the workshop.

Therefore, in the course of brain storm for the solution idea, two aspects have to be considered. Firstly, changing components which is already installed in the machine will not only derive additional cost on redesign and replacement, but also the following adjustment to the new parts may affect the performance or even lead to a malpractice of the design. Secondly, while installing an external device or extra parts to the machine, too much additional mass directly loaded on main body of the machine should be avoided. The limited space left within the welding head should be well exploited so that the volume of modified machine will not be too bulky.

From a video about the real machine working, the situation of the limited space left within the machine and the location of the welding head to the main body (conveyor for the film passing by) is studied. The machine is compact and the distance where the wheel (gear) is assembled, from the supporting board to the crossbar, is short.

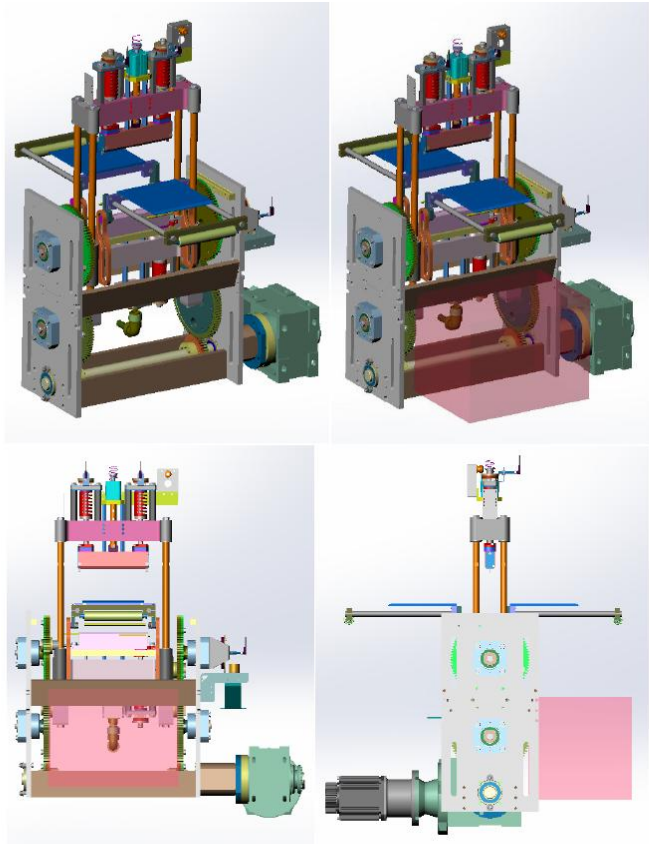

Fig. 5: CAD model of the original machine

It means no extra space for directly adding a counter weight on the same wheel where welding bars are located. However, besides the inside and outside of the welding head, there is some free space under the conveyor, between the welding head and main body of the machine. In Fig. 5, the transparent area in red represents the area which is free to be used.

Since these constraints, to balance out the inertia force of the mass, two solutions can be proposed and discussed. Both these two solutions are to engage one more rotating mass to each wheel, the upper one and the lower one. These two additional masses rotate together with the existing two wheels through certain mechanical links and therefore compensate the inertia force of the welding units. The difference of the two solutions is the rotation direction of the upper balance weight. In the first solution, as is described in Fig. 6a, the upper balance weight does not rotate on an opposite direction, but on a same direction with the upper wheel. The upper balance units are connected to the upper wheel through a timing belt which can guarantee the consistency of the transmitted speed.

Consequently, the two balance weights rotate with same speed and the inertia forces produced by them on vertical direction are not compensated by each other as it is in the first solution. However, the critical issue which produces most vibration is the component of inertia on the horizontal direction, while the vertical component of inertia force is relatively low compared to the gravity of the whole machine and not prominent. With this layout, rotating with the same speed has the advantage of less rotational inertia and, as a result, the reaction force applied on each joint between the board and shaft decreases.

Contrarily in the second solution, in Fig. 6b, both the upper balance weights and lower balance weight are fixed on an identical gear as the existing wheels and are all connected through gear connection. As a result, the direction of rotational velocity of each balance weight is opposite to whose it is balancing. In this case, on both the horizontal and vertical direction, the inertia force produced could be balanced out with an amount depending on the ratio of weight and inertia of moment between the welding units and their balance units.

As regards to the lower balance weight, it occupies the space remained on the bottom of machine and is engaged by gear connection. The weight of welding units on the lower wheel is assumed to be equal to 25 kg. Thanks to the precious space, it is possible to apply a relatively heavy balance mass. Without the constraint of limited space, increasing the volume of the additional mass to achieve a better performance would become easier.

IV. 3D MODEL BUILDING AND VERIFICATION OF ADAMS MODEL

In order to have a reliable calculation of the improvement carried by each solution and to make a comparison between them, it is necessary and crucial to build up a model of the mechanism before any modifications, for first simulation and verification. The necessity can be explained twofold.

The primary reason is that the simulation result cannot offer any validity until the model can run without any obvious physical inconsistency as well as the characteristic quantities are relevant to the values from mathematical calculation. Otherwise, we cannot conclude that the further simulations of different solutions implemented are qualified. The other reason is the value of the tested model itself. The data earned from model of original machine can provide the reference for the following simulations analysis.

As shown in Fig. 9, the red parts are the two supporting boards on both sides. The blue parts represent the welding units, the crossbars where the springs and welding jaws are assembled. The geometry of gears on the motor pulley, lower wheels, and upper wheels are not presented in the model. So, there are three pairs of wheels with shaft as a whole which are all in green.

When the simulations are about to run, the motor shaft with pulleys on it moves the green bars with two wheels on the bottom, giving them the designed rotational motion law and the motor shaft drives all these pairs of green wheels and puts in movement the welding units in blue. All these parts are constrained by different joints defined in ADAMS environment according to the real situation of how the machine is working in practice.

A. Preliminary simulation and discussion of solution with timing belt (Solution1)

In this paragraph is discussed the 3D model built in ADAMS of the solution of adding upper balance weight by employing timing belt and used to run the simulation. With this model, it is possible in the end to learn the general effects from this modification.

Moreover, by simply controlling the different parts within the ADAMS 3D model to be activated or deactivated while running the simulation, it is possible to study separately the effect from each balance weight added

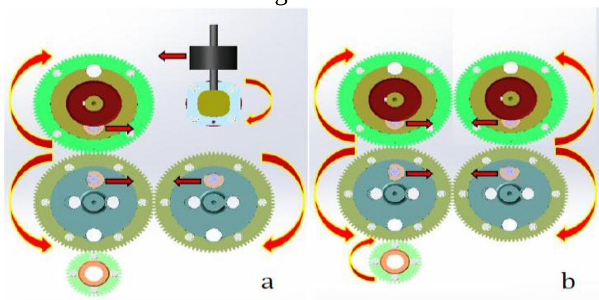

Fig. 6: Mechanism of two possible solutions

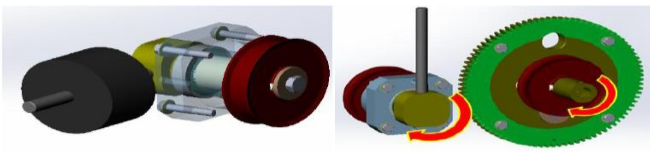

Fig. 7: Mechanism of upper balance unit

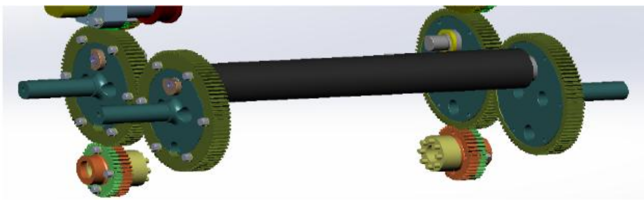

Fig. 8: Mechanism of upper balance unit

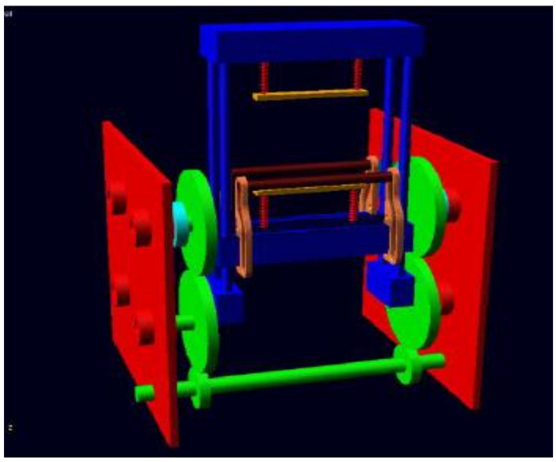

Fig. 9: 3D model of original machine in ADAMS

and its pattern of changing the property itself. The solution of adding balance weight up and down through connecting the upper balance weight with

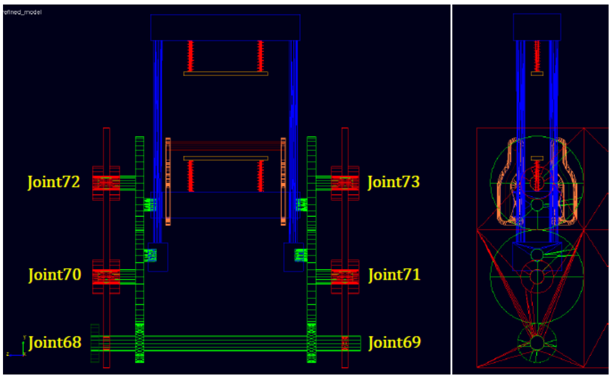

Fig. 10: Locations of the tested joints in the model

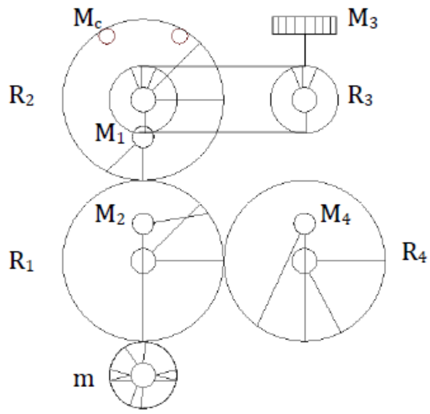

Fig. 11: Diagram of the mechanism of Solution 1

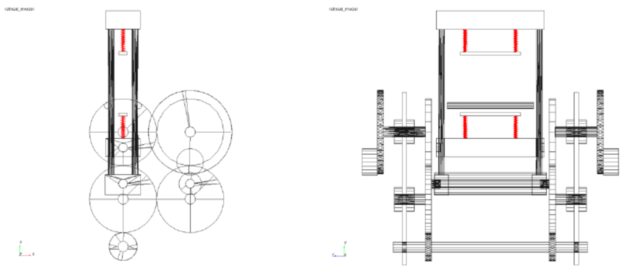

Fig. 12: Scheme of the mechanism of Solution 2

timing belt is described in Fig. 11.

Therefore, the configuration obliges both the upper and lower balance weights to rotate simultaneously with the same rotational speed of the upper wheels which carry the welding units M2. In this case, the horizontal component of inertia forces of the welding units, M1 and M2, are expected to be balanced out from the system by the ones derived from added balance weights, M3 and M4, on top and on the bottom respectively. The balance weights on top are 2.5 kg each, 5 kg in total, while the lower balance weight is set to 10 kg. Mc is set to be 1 kg. r3 is 104 in length, twice the time of r which is 52 mm.

B. Preliminary simulation and discussion of solution with gear connection (Solution 2)

Fig. 12 shows the configuration of the solution with upper

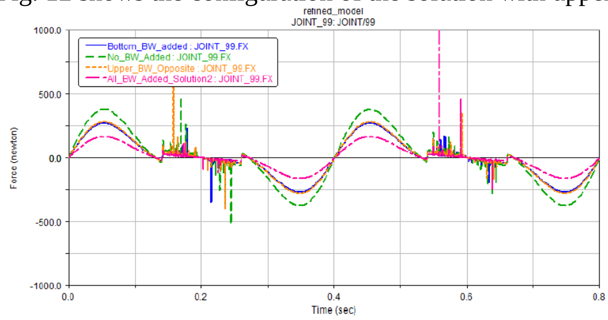

Fig. 13: Horizontal reaction force of the whole machine

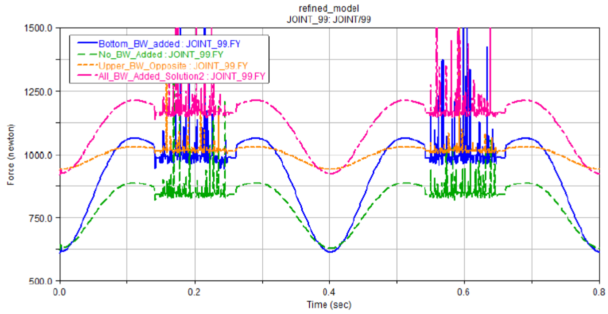

Fig. 14: Vertical reaction force of the whole machine

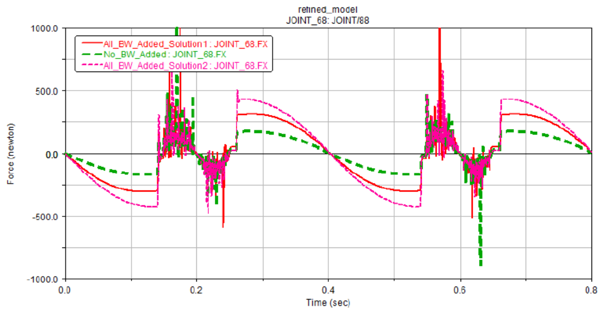

Fig. 15: Comparison of horizontal reaction force in Joint68 between two solutions

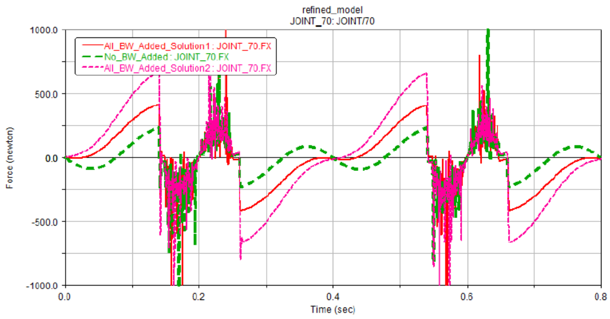

Fig. 16: Comparison of horizontal reaction force in Joint70 between two solutions

balance weights connected to the upper wheels by gear connection. Different from the case in solution which employs timing belt instead, the upper balance weights rotate with the opposite direction of the upper wheels.

Fig. 13 and Fig. 14 are respectively the horizontal component and vertical component of the total reaction force of the whole machine.

On the horizontal direction, the effect of this solution is same as the one discussed previously, having the decrease up to 56% of the total reaction force.

On the vertical direction

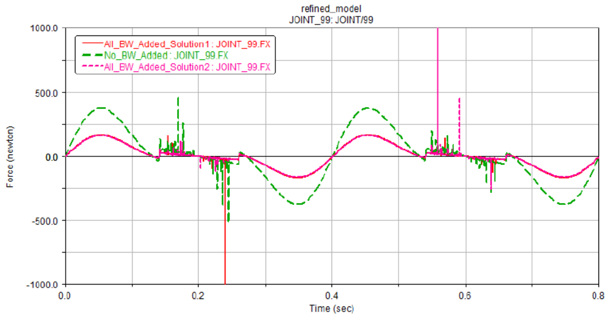

Fig. 17: Comparison of horizontal reaction force the machine between two solutions

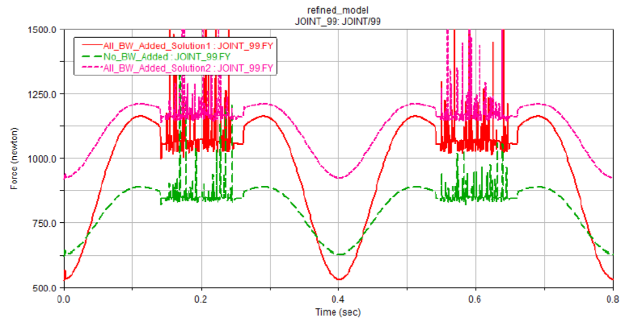

Fig. 18: Comparison of vertical reaction force of the machine between two solutions

Items to be increased or implemented	Stress in Joints	Horizontal vibration of the machine (reaction force)	Vertical vibration of the machine (reaction force)
Counterweight	↑	↓	↑
Moment of Inertia	↑	——	↑
Synchronous rotation	↑	——	↑
Opposite rotation	↑	——	↓

* ↑ increase; ↑ slightly increase; ↓ decrease;

Fig. 19: Comparison of the dynamical effects of discussed changes

(Fig. 14), the simulation in which only the upper balance weight is activated (the curve in orange) and the simulation with all balance weights added (curve in magenta) shows a good control on variation range from the upper balance weight though it increases the load dramatically (by more or less 25%).

V. COMPARISON BETWEEN THE TWO SOLUTIONS

In Fig. 15,16 and 17, the red curves stand for the reaction force detected in simulation of solution with the timing belt, which is symbolized as Solution 1. The curves in magenta are the other solution of connecting upper balance weights by gears, which is named Solution 2. The green curves are as mentioned before the original machine model without any balance weights.

Within each joint, as what have already shown in the previous paragraphs, adding the balance weights will increase the loads on each joint. But it is also seen that solution 2 have a more remarkable effect on the joint than solution 1 does. It could be the due to the different configurations and parts are assembled to realize the modification, for instance, the moment of inertia from the upper balance units or the weight of these additional components.

In Fig. 17, it can be observed that on horizontal direction both the solutions have the same improvement in decreasing the vibration. The curves describing the behaviors of the reaction force applied on the machine are overlapped. However, the situation on vertical direction is different. In Fig.18, it can be observed that Solution 1 causes a worse condition of larger vibration on vertical direction.

On the contrary, Solution 2 almost doesn't change the shape of the curve from the original machine, which means, no additional vibration happens, though it increases the static force due to the additional gravity.

VI. CONCLUSION

A flow pack mechanism has been studied through multibody simulations with the aim of evaluating the possibility of adding balance weights for reducing vibration of the welding head.

Different design solutions have been considered and the results of the two more significant are here reported. The role of such simulation is to assist the designer in calculating the dimension and the position of the counterweights to be added. Indeed, to eliminate vibration due to the eccentric rotating mass, the counterweights should be proper located and designed: too large of the balance weights would lead to problem of over-balance and too small of the balance weights or a non-ideal location would lead to invalid result.

Besides, less moment of inertia of the additional parts and components in the balancing system is preferred. The analysis method proved to be adequate to the project needs, however, the limitations of simulating in ADAMS should not be neglected. All bodies in ADAMS 3D model are regarded perfectly rigid.

The effects of the elasticity and deformation are not considered within the simulation. In other word, the simulations run in ADAMS offer us a brief understanding and indications on how the machine prototype and parts will behave, they cannot represent the real performance of the machine.

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