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ORIGINAL ARTICLE

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An investigation into design and manufacturing of mechanical conveyors systems for food processing

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Abstract This paper presents the results of a research investigation undertaken to develop methodologies and techniques that will reduce the cost and time of the design, manufacturing and assembly of mechanical conveyor systems used in the food and beverage industry. The improved methodology for design and production of conveyor components is based on the minimisation of materials, parts and costs, using the rules of design for manufacture and design for assembly. Results obtained on a test conveyor system verify the benefits of using the improved techniques. The overall material cost was reduced by 19% and the overall assembly cost was reduced by 20% compared to conventional methods.

Keywords Assembly · Cost reduction · Design · DFA · DFM · Mechanical conveyor

1 Introduction

Conveyor systems used in the food and beverage industry are highly automated custom made structures consisting of a large number of parts and designed to carry products such as food cartons, drink bottles and cans in fast production and assembly lines. Most of the processing and packaging of food and drink involve continuous operations where cartons, bottles or cans are required to move at a controlled speed for filling or assembly operations. Their operations require highly efficient and reliable mechanical conveyors, which range from overhead types to floor-mounted types of chain, roller or belt driven conveyor systems.

In recent years, immense pressure from clients for low cost but efficient mechanical conveyor systems has pushed conveyor manufacturers to review their current design and assembly methods and look at an alternative means to manufacture more economical and reliable conveyors for their clients. At present, most material handling devices, both hardware and software, are highly specialised, inflexible and costly to configure, install and maintain [1]. Conveyors are fixed in terms of their locations and the conveyor belts according to their synchronised speeds, making any changeover of the conveyor system very difficult and expensive. In today's radically changing industrial markets, there is a need to implement a new manufacturing strategy, a new system operational concept and a new system control software and hardware development concept, that can be applied to the design of a new generation of open, flexible material handling systems [2]. Ho and Ranky [3] proposed a new modular and reconfigurable 2D and 3D conveyor system, which encompasses an open reconfigurable software architecture based on the CIM-OSA (open system architecture) model. It is noted that the research in the area of improvement of conveyor systems used in beverage industry is very limited. Most of the published research is directed towards improving the operations of conveyor systems and integration of system to highly sophisticated software and hardware.

This paper presents a research investigation aimed at improving the current techniques and practices used in the design, manufacturing and assembly of floor mounted type chain driven mechanical conveyors in order to reduce the manufacturing lead time and cost for such conveyors. Applying the concept of concurrent engineering and the principles of design for manufacturing and design for assembly [4, 5], several critical conveyor parts were investigated for their functionality, material suitability, strength criterion, cost and ease of assembly in the overall conveyor system. The critical parts were modified and redesigned with new shape and geometry, and some with new materials. The improved design methods and the functionality of new conveyor parts were verified and tested on a new test conveyor system designed, manufactured and assembled using the new improved parts.

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2 Design for manufacturing and assembly (DFMA)

In recent years, research in the area of design for manufacturing and assembly has become very useful for industries that are considering improving their facilities and manufacturing methodology. However, there has not been enough work done in the area of design for conveyor components, especially related to the issue of increasing numbers of drawing data and re-engineering of the process of conveyor design based on traditional methods. A vast amount of papers have been published that have investigated issues related to DFMA and applied to various methodologies to achieve results that proved economical, efficient and cost effective for the companies under investigation.

The main classifications of DFMA knowledge can be identified as (1) General guidelines, (2) Company-specific best practice or (3) Process and or resource-specific constraints. General guidelines refer to generally applicable rules-of-thumb, relating to a manufacturing domain of which the designer should be aware. The following list has been compiled for DFM guidelines [6].

- Design for a minimum number of parts
- Develop a modular design
- Minimise part variations
- Design parts to be multifunctional
- Design parts for multiuse
- Design parts for ease of fabrication
- Avoid separate fasteners
- Maximise compliance: design for ease of assembly
- Minimise handling: design for handling presentation
- Evaluate assembly methods
- Eliminate adjustments
- Avoid flexible components: they are difficult to handle
- Use parts of known capability
- Allow for maximum intolerance of parts
- Use known and proven vendors and suppliers
- Use parts at derated values with no marginal overstress
- Minimise subassemblies
- Emphasise standardisation
- Use the simplest possible operations
- Use operations of known capability
- Minimise setups and interventions
- Undertake engineering changes in batches

These design guidelines should be thought of as "optimal suggestions". They typically will result in a high-quality, low-cost, and manufacturable design. Occasionally compromises must be made, of course. In these cases, if a guideline goes against a marketing or performance requirement, the next best alternative should be selected [7].

Company-specific best practice refers to the in-house design rules a company develops, usually over a long period of time, and which the designer is expected to adhere to. These design rules are identified by the company as contributing to improved quality and efficiency by recognising the overall relationships between particular processes and design decisions. Companies use such guidelines as part of the training given to designers of products requiring significant amounts of manual assembly or maintenance. Note that most of the methodologies are good at either being quick and easy to start or being more formal and quantitative. For example, guidelines by Boothroyd and Dewhurst [8] on DFA are considered as being quantitative and systematic. Whereas the DFM guidelines, which are merely rules of thumb derived from experienced professionals, are more qualitative and less formal [9].

3 Conventional conveyor system design

Design and manufacturing of conveyor systems is a very complex and time-consuming process. As every conveyor system is a custom-made product, each project varies from every other project in terms of size, product and layout. The system design

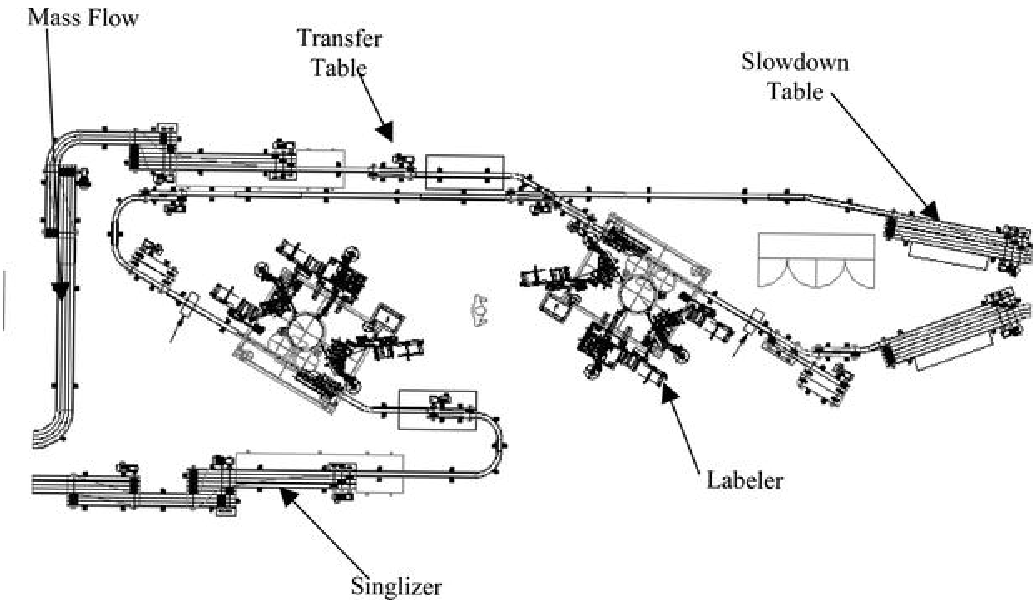

Fig. 1. Layout of conveyor system for labelling plasic bottles

is based on client requirements and product specifications. Moreover, the system layout has to fit in the space provided by the company. The process of designing a layout for a conveyor system involve revisions and could take from days to months or in some instances years. One with the minimum cost and maximum client suitability is most likely to get approval.

Figure 1 shows a schematic layout of a typical conveyor system installed in a production line used for labelling of plastic bottles. Different sections of the conveyor system are identified by specific technical names, which are commonly used in similar industrial application. The "singlizer" section enables the product to form into one lane from multiple lanes. The "slowdown table" reduces the speed of product once it exits from filler, labeller, etc. The "mass flow" section is used to keep up with high-speed process, e.g., filler, labeller, etc. The "transfer table" transfers the direction of product flow. The purpose of these different conveyor sections is thus to control the product flow through different processing machines.

A typical mechanical conveyor system used in food and beverage applications consists of over two hundred mechanical and electrical parts depending on the size of the system. Some of the common but essential components that could be standardised and accumulated into families of the conveyor system are side frames, spacer bars, end plates, cover plates, inside bend plates, outside bend plates, bend tracks and shafts (drive, tail and slave). The size and quantity of these parts vary according to the length of conveyor sections and number of tracks corresponding to the width and types of chains required. The problems and shortcomings in the current design, manufacturing and assembly of mechanical conveyors are varied, but include:

- Over design of some parts
- High cost of some components
- Long hours involved in assembly/maintenance
- Use of non-standard parts

4 Areas of improvement

In order to identify the areas of cost reduction in material and labour, a cost analysis of all main conveyor parts was conducted to estimate the percentage of cost of each part in relation to the total cost of all such parts. The purpose of this analysis was to identify the critical parts, which are mainly responsible for increasing the cost of the conveyor and thereby investigate means for reducing the cost of such parts.

Table 1 shows the cost analysis of a 50-section conveyor system. The analysis reveals that 12 out of 15 parts constitute 79% of the total material cost of the conveyor system, where further improvements in design to reduce the cost is possible. Out of these, seven parts were identified as critical parts (shown by an asterisk in Table 1) constituting maximum number of components in quantity and comprising over 71% of overall material cost. Among these, three components (leg set, side frame and support channel) were found to account for 50% of the total conveyor material cost. A detailed analysis of each of these 12 parts was carried out considering the principles of concurrent engineering, design for manufacture and design for assembly, and a new improved design was developed for each case [10]. Details of design improvement of some selected major component are presented below.

5 Redesign of leg set assembly

In a conveyor system, the legs are mounted on the side frame to keep the entire conveyor system off the floor. The existing design of conveyor legs work, but they are costly to manufacture, they have stability problems, and cause delays in deliveries. The delay is usually caused by some of the parts not arriving from overseas suppliers on time. The most critical specifications required for the conveyor legs are:

Table 1. Conveyor critical parts based on parts cost analysis

Product description	Qty	Material used	Cost (%)	Improvement possible (Yes/No)
Leg set*	68	Plastic leg + SS tube	20.22	Yes
Side frame*	80	2.5 mm SS	16.07	Yes
Support channel*	400	C channel SS	15.00	Yes
Bend tracks	8	Plastic	14.36	No
Rt. roller shaft*	139	20 dia. SS shaft	6.70	Yes
Tail shaft	39	35 dia. Stainless steel	6.27	No
Spacer bar*	135	50X50X6 SS	5.43	Yes
Support wear strip*	400	40 × 10 mm plastic	5.36	Yes
Support side wear strip*	132	Plastic	3.01	Yes
End plate	39	2.5 mm/SS	1.88	Yes
Cover plate	39	1.6 mm S/S	1.57	No
Bend plates	8	2.5 mm/SS	1.29	Yes
Torque arm bracket	18	6 mm S/S plate	1.21	Yes
Slot cover	97	Stainless steel	0.97	Yes
Inside bend plate	8	2.5 mm/SS	0.66	Yes
Total			100.00	

*Critical parts

- Strength to carry conveyor load
- Stability
- Ease of assembly
- Ease of flexibility (for adjusting height)

Figure 2 indicates all the parts for the existing design of the conveyor leg. The indicated numbers are the part numbers described in Table 2, which also shows a breakdown of cost analysis complete with the labour time required to assemble a complete set of legs. The existing leg setup consists of plastic leg brackets ordered from overseas, stainless steel leg tubes, which are cut into specified sizes, leg tube plastic adjustments, which are clipped onto the leg tube at the bottom as shown in Fig. 2. Lugs, which are cut in square sizes, drilled and welded to the leg tube to bolt the angle cross bracing and backing plate to support leg brackets bolts. The # of parts in Table 2 signifies the number of components in each part number and the quantity is the consumption of each part in the leg design. Companies have used this design for many years but one of the common complaints reported by the clients was of the instability of legs.

From an initial investigation, it became clear that the connection between the stainless steel tube and plastic legs bracket (part 1 and part 3 in Fig. 2) was not rigid enough. The connections for these parts are only a single 6 mm bolt. At times, when the conveyor system was carrying full product loads, it was observed that the conveyor legs were unstable and caused mechanical vibration. One of the main reasons for this was due to a single bolt connection at each end of the lugs in part 3 and part 7. The stability of the conveyor is considered critical matter and requires rectification immediately to satisfy customer expectations.

Considering the problems of the existing conveyor leg design and the client's preferences, a new design for the conveyor leg was developed. Generally the stability and the strength of the legs were considered as the primary criteria for improvement in the new design proposal but other considerations were the simplicity of design, minimisation of overseas parts and ease of assembly at the point of commissioning. Figure 3 shows, the new design of the conveyor's leg assembly, and Table 3 gives a description and the cost of each part.

Figure 3 shows that the new design consists of only five main parts for the conveyor's leg compared to eight main parts in the old design. In the old design, the plastic leg bracket, the leg tube plastic adjustment and the leg tube were the most expensive items accounting for 72% of the cost of leg assembly. In the new

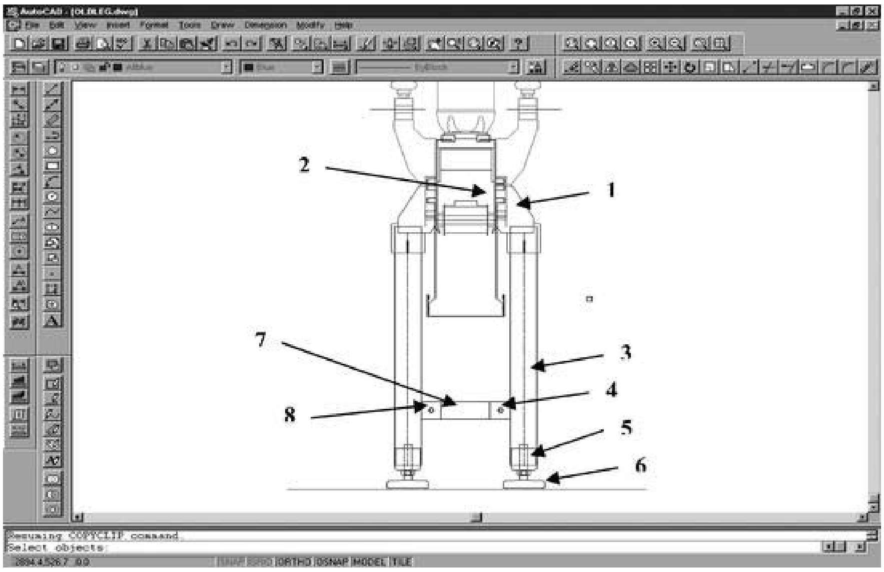

Fig. 2. Existing leg design assembly with part names shown in Table 1

Table 2. Cost analysis for old leg design assembly

Part no.	Part description	# of parts	Qty	Cost	Source
1	Plastic leg bracket	2	2	$ 30.00	Overseas
5, 6	Leg tube plastic adjustment	4	2	$ 28.00	Overseas
4	Lug	2	2	$ 4.00	In-house
7	Angle cross bracing	1	1	$ 5.00	In-house
2	Backing plate	2	2	$ 4.00	In-house
3	Leg tube	2	2	$ 25.00	In-house
8	Bolts	6	6	$ 3.00	In-house
	Total assembly cost (welding)			$ 15.00	In-house
	Total	19	17	$ 114.00	

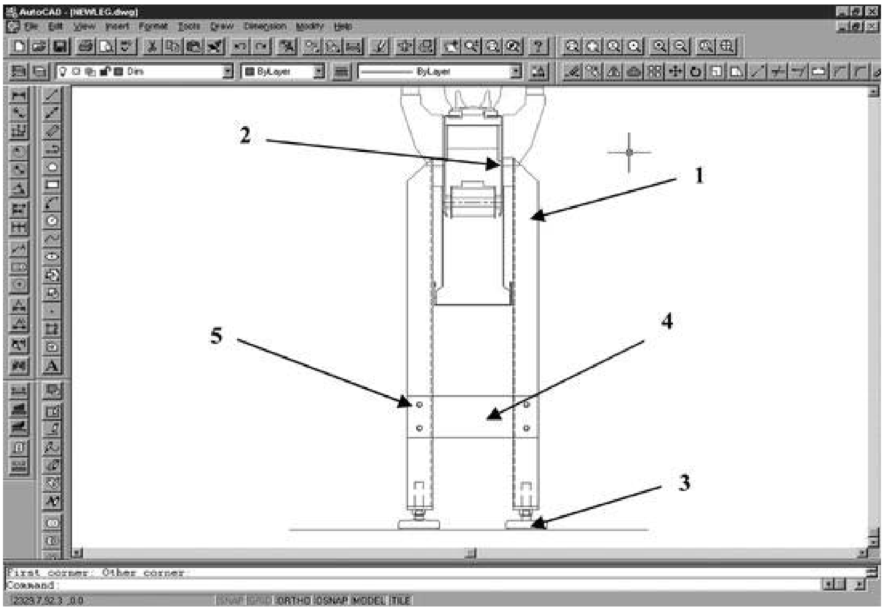

Fig. 3. New design for leg assembly with part names in Table 3

Table 3. Cost analysis for new design leg assembly

Part no.	Part description	# of parts	Qty	Cost	Source
1	Stainless steel angle (50 × 50 × 3 mm)	2	2	$ 24.00	In-house
3	Leg plastic adjustment	2	2	$ 10.00	Overseas
4	Cross brassing	1	1	$ 7.00	In-house
5	Bolts	8	4	$ 4.00	In-house
2	Backing plate	2	2	$ 4.00	In-house
	Total assembly cost			$ 10.00	In-house
	Total	15	11	$ 59.00	

design, those parts have been replaced by a stainless steel angle and a new plastic leg adjustment reducing the cost of leg assembly by almost 50%. Thus the total numbers of parts in the leg have been reduced from 19 to 15 and the total cost per leg setup has been reduced by $ 55 in the new design.

The new conveyor leg design, when tested, was found to be more secure and stable than the old design. The elimination of part number 1 and 5 from old conveyor design has made the new design more stable and rigid. In addition, the width of the cross bracing has also been increased with two bolts mount instead of one in old design. This has provided the entire conveyor leg setup an additional strength.

6 Redesign of the side frames

The side frame is the primary support of a conveyor system that provides physical strength to conveyors and almost all the parts are mounted on it. The side frame is also expected to have a rigid strength to provide support to all the loads carried on the conveyor. It also accommodates all the associated conveyor components for the assembly. The critical considerations of side frame design are:

- Size of side frame (depth)
- Strength of the material
- Ease for assembly
- Ease for manufacturing

Figure 4 shows the side frame dimension and parameters. The side frame used in existing design appears to be of reasonable depth in size (dimension H in Fig. 4). From the initial investigation, it was found that the distance between spacer bar holes and return shaft (dimensions G and F in Fig. 4) could be reduced, as there was some unnecessary gap between those two components. The important point to check before redefining the design parameters was to make sure that after bringing those two closer, the return chains would not catch the spacer bar while the conveyor is running. The model of the new side frame design was drawn on CAD to ensure all the specifications are sound and the parts are placed in the position to check the clearances and the fits. Using the principle of design for manufacturing the new side frame design was made symmetrical so that it applies to all types of side frames. This change is expected to reduce the size of side frame significantly for all sizes of chains.

Table 4 shows a comparison of dimensions in the old design and the new design of side frames for the same chain type. It

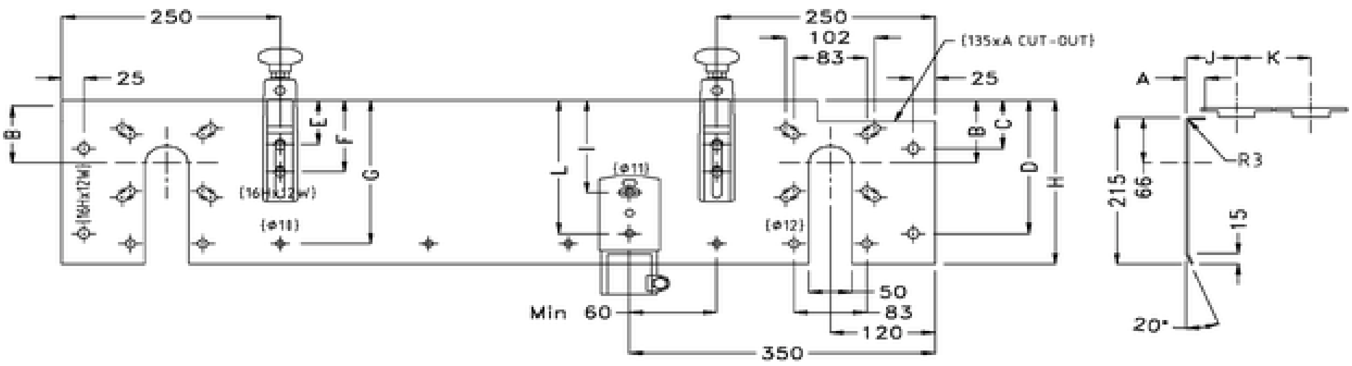

Fig. 4. Side frame dimensions

Table 4. New and old side frame dimension parameters

Old design													
Chain type		A	B	C	D	E	F	G	H	I	J	K	L
3.25″ LF/SS	STR/LBP/MAG	31	92	71	196	65	105	211	241	136	58	85	196
	TAB	22	83	62	187	56	96	202	232	127			
New design													
Chain type		A	B	C	D	E	F	G	H	I	J	K	L
3.25″ LF/SS	STR/LBP/MAG/TAB	31	100	73	173	67	107	167	199	92	58	85	152

is noted that the overall size (depth) of the conveyor has been reduced from 241 mm to 199 mm (dimension H), which gives a saving of 42 mm of stainless steel on every side frame manufactured. Thus, from a stainless steel sheet 1500 × 3000 mm, the old design parameters allowed only six 3 m long side frames but with the new design parameter now it was possible to produce seven side frames of 3 m long from the same sheet size.

The amount of material used for side frames was also reviewed for further investigation. It is estimated that about 55% of the total cost of the conveyor system is spent on materials. The current material used for side frames is 2.5 mm thick stainless steel food grade 304. Currently, there are other materials available in the market with alternative thickness that could be considered as an option. For this, a deflection analysis has been conducted to estimate if there was any other type of material suitable to replace the existing material so that it does not fail its strength criteria.

6.1 Deflection analysis for side frames

Figure 5 shows the experimental setup to determine the deflection of new side frame in X and Y direction under different loading conditions. With the new design parameters a set of side frames were manufactured to investigate the deflection on 1.6 mm thick stainless steel side frames. A section of side frame bolted with spacer bar and return shaft was assembled for testing with the experiment. The results for deflection were obtained by applying variable loads on a section of the side frame via a hydraulic press. As shown in Fig. 5, the deflection gauges are placed on vertical (Y) and horizontal (X) axes to measure any reading observed on the side frames. The loads are applied on side frame via the hydraulic press in downward direction. The side frames are supported by stands from the same position where the legs are mounted on the side frames.

Three sets of experiments are conducted on four, six and eight tracks of conveyor sections to observe any abnormalities under big loads. The loads applied on the experimental conveyor sections are over estimated and are higher than actual load conditions for conveyor system in real applications. The conveyors are usually designed to carry load under one tonne per metre for industry application in the food and beverage industry. The purpose of applying a big load was to estimate the point of deflection for side frame under high loads. Figures 6 and 7 show the results of the experiments for the conveyor sections of four tracks and six tracks, respectively.

From the results obtained, it is observed that under 2 KN of loads, the deflection values are almost under 2 mm for all

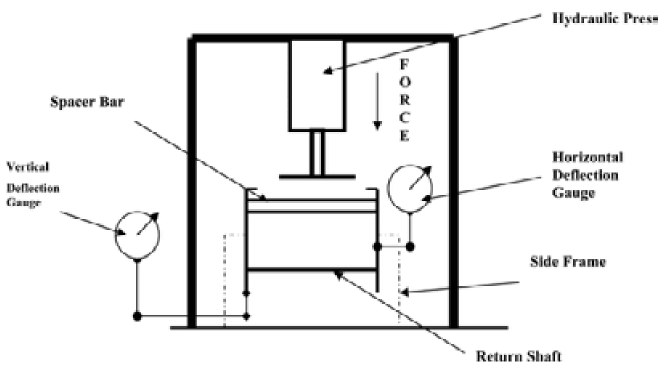

Fig. 5. Experimental set up to investigate deflection on new side frame design

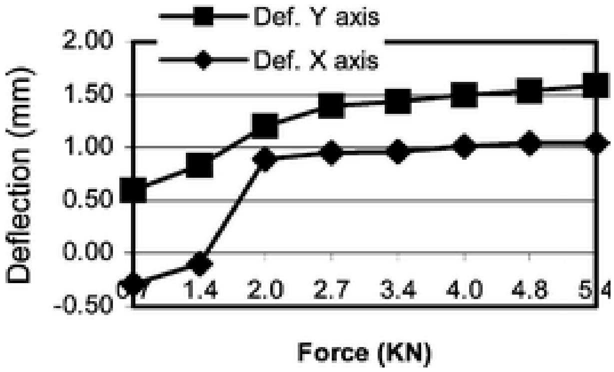

Fig. 6. Deflection results for 4-track 1.6 mm stainless steel side frame

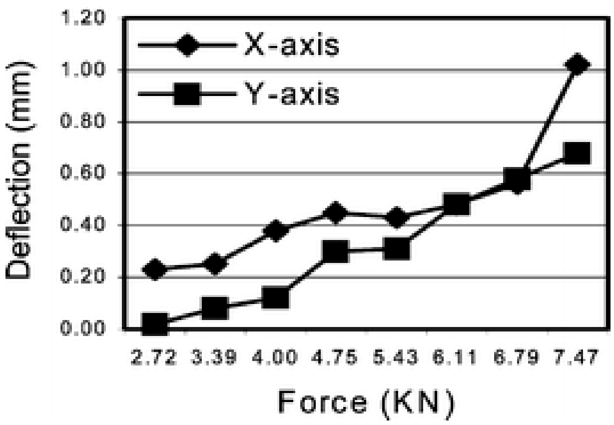

Fig. 7. Deflection results for 6-track 1.6 mm stainless steel side frame

types of sections. Under the given circumstances, the 1.6 mm stainless steel side frame design can be a possible alternative to the existing conveyor side frame design. It is expected that with wider conveyor sections, the deflections on side frame will stay within the allowable limits, that is, ±5 mm. The main reason why this experiment was conducted is to ensure that the side frames do not buckle under high loads. Thus there was no evidence of buckling occurrence for any of the types of conveyor sections used. It is also expected, based on the experiences of engineers and the investigation during the current research, that after the complete assembly is made, the conveyors will conceive additional strength, which will further reduce the possibility of deflection on the side frame. The deflection, for instance, was measured for each set of experiments outwards. With the leg mounted on the side frame, the forces will act in opposite direction that will push the side frame inwards. The full observation of this assumption can be concluded when a complete test conveyor is manufactured and tested based on new design parameters.

With all the results obtained from the experiments, it is concluded that 1.6 mm stainless steel grade 304 side frames can be manufactured for conveyors for food and beverage industry under the specified guidelines for loads. The cost saving made in this area is expected to be significant since 80% of material used in a conveyor system is made of stainless steel.

Table 5. Cost analysis for side frame

Side frame cost analysis for old design			
Product/process description	Material	Qty	Cost
Side frame (3000 × 241 mm @$ 360 per sheet)	2.5 mm	1	$ 60.00
Slot (50 cent per slot punch)		8	$ 4.00
Holes (20 cent per hole punch)		30	$ 6.00
Fold		2	$ 3.00
Total cost			$ 73.00
Side frame cost analysis for new design			
Product/process description	Material	Qty	Cost
Side frame (3000 × 199 mm @$ 162 per sheet)	1.6 mm	1	$ 23.00
Slot (50 cent per slot punch)		8	$ 4.00
Holes (20 cent per hole punch)		30	$ 6.00
Fold		2	$ 3.00
Total cost			$ 36.00

6.2 Side frame cost analysis

The material review and deflection analysis has shown that the existing 2.5 mm stainless steel sheet was an over design for side frame for the food and beverage conveyor application. The analysis also showed that 1.6 mm thick stainless steel sheet can be used as an alternative material for the side frame, which will perform its function satisfactorily. Table 5 shows a comparison of the costing of the old and new design of side frames, which shows that the saving per side frame on the new design is expected to be $ 37 (i.e., a savings of 50.1%).

In addition to this cost saving, the reduction of side frame size from 241 mm to 199 mm will also allow the production of one extra side frame out of the 3000 × 1500 mm stainless steel sheet.

New design improvements were also carried out in several other critical parts such as support channel, return roller shaft, spacer bar, support wear strip and support side wear strip, which resulted in further cost and labour savings and also ease of manufacturing and assembly. For example, the new design of support channel assembly (including support wear strip and side wear strip) required reduced number of processes, reduced wear strip thickness, use of a new M section channel and provision for use with different types of chains giving a cost saving of 33.7% in this improved design. The new design of return roller shaft offered a cost savings of 44.5% and a 50% reduction in labour time. The new design of the spacer bar offered an estimated cost saving of 25% from the old design.

7 Design implementation in a test conveyor system

The implementation of design improvements of individual critical parts and components was carried out in the design, manufacturing and assembly of a full-fledged test conveyor system. This new and improved test conveyor was then tested and verified for performance with actual products (plastic bottles). A cost analysis was also conducted to compare the overall cost savings in this test conveyor with the costs involved with an identical conveyor based on old design [7].

The new test conveyor is a singleiser type (Fig. 8), comprises of three different sections with a total length of 5 m. Section C1 is a six-track conveyor section joined to section C2, which is a six-track 90° bend conveyor. This is connected to conveyor section C3, which is an eight-track conveyor section with combination of two different types of chains, TAB and STR. The test conveyor contains a total of 26 major parts. Figure 9 shows the test conveyor used for testing of product flow at the collaborating company.

The performance and efficiency of the new test conveyor and its critical new parts were tested for smooth, noiseless performance by observing the product flow of empty plastic drink bottles on the conveyor. All the parts and the conveyor system were found to show fully functional satisfactory performance.

A complete cost analysis on the test conveyor was conducted to measure the difference between old and new designs and also to evaluate the ease in assembly and reduction in labour expenditure. Quantity of parts, the material used, and the manufacturing costs were calculated for each part and percentage savings of each part and the overall system were determined.

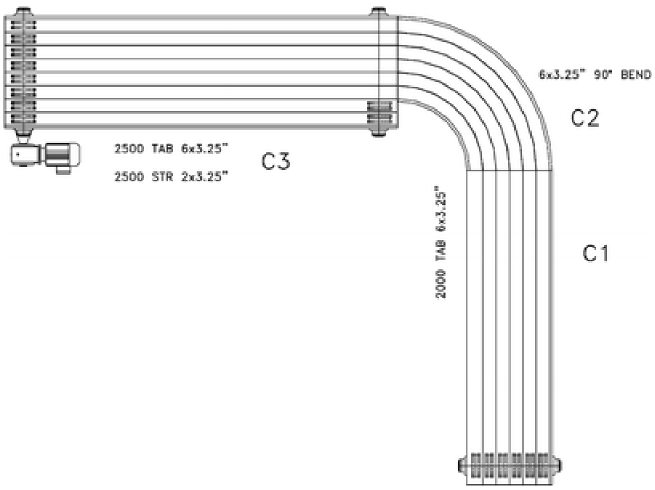

Fig. 8. A singliser test conveyor

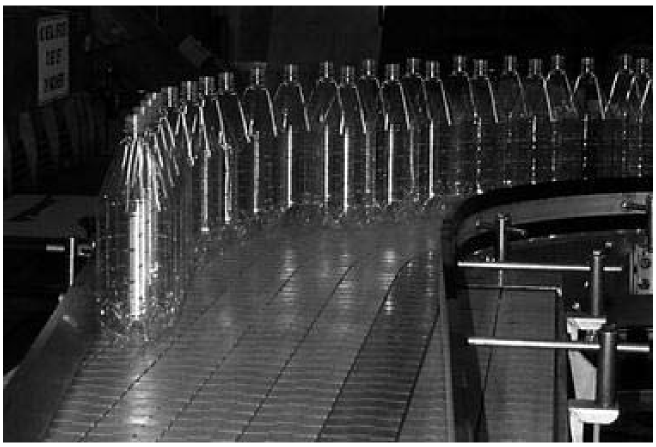

Fig. 9. Test conveyor assembly: product flow test

8 Results and discussion

The most critical area of consideration was to check if the new support channel setup and the drip tray joining were carried out with less labour consumption. Attention was also paid to make sure that the labourers have been working effectively on the job. The times used for the assembly of conveyor system are expected to vary depending on the mood of workers and other external factors. But efforts were made to achieve the closest possible time to manufacture the conveyors.

A study of cost analysis reveals the following facts:

- A manufacturing cost saving of 40% or more was achieved in eight out of 12 of the improved design parts. A cost saving of 26% to 34% was achieved in other three parts.
- Among the high cost parts, the maximum savings were achieved for the side frame, return roller shaft, leg set and support wear strips.
- The overall cost of the conveyor was reduced by 19%.
- The overall cost of labour in the assembly of the conveyor was reduced by 20%.

It is observed that the savings accomplished are mainly achieved for the conveyor parts that had been over designed or are not professionally designed. One of the major changes that affected the design of conveyor system was the revision of the side frame design parameters, which also affected the changes in other parts that were allied with it. Secondly, the development of new M profile support channel along with the standard wear strips added to major achievement in the new conveyor design. The accomplishment from the new design reduced the labour cost and also made significant impact on the assembly line for improved design and manufacture. It was also noticed that by categorising the spacer bars for different number of tracks improved the selection procedure for the design. The new conveyor system became more economical and cost effective and the need to use extra strength materials was eliminated.

9 Conclusions

In the design and manufacturing of mechanical conveyor systems, there is a considerable dearth of research work in conveyor design optimisation and especially a lack of application of modern techniques to the design improvement in such systems. In order to improve the costs and lead times in the conveyor system, a complete breakdown analysis of a test conveyor has been conducted to evaluate the high spending areas in conveyor manufacturing. The analysis was supported by applying principles of design for manufacturing and design for assembly for improving the design without sacrificing the functionality and operation of the system. A new conveyor design was proposed based on all the recommended modifications of conveyor components. The recommendations were verified on a test conveyor system and adopted by the collaborating company. The results proved successful with a 19% overall savings in cost and 20% reduction in total labour cost. The research results confirm that by applying the rules of DFMA, the cost of design and assembly of a complex system like the mechanical conveyors for food processing can be drastically reduced.

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