Manufacture of High Quality Musical Steel Drums in Trinidad and Tobago

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Abstract

This paper explores innovative manufacturing processes, which can be used to manufacture the national musical instrument of Trinidad and Tobago, the Musical Steel Drum or Steel Pan. The main manufacturing process used today is the manual hand-forming technique. In order to achieve more consistent and deeper formed components while maintaining the high quality of the instrument, it is proposed that the Marforming process and the Flow-forming process, an adaptation of the Spinforming process, be used more frequently in the future to replace the traditional Hand-forming method. In the traditional Spinforming technique material is pushed from the outer circumference of the metal disc to the center in progressive passes of the former. This results in a thinning of the outer region of the formed component with thickening of the center, however the opposite is required for the musical steel drum and by adapting the process the required strain distributions were achieved. Evaluation took the form of strain analyses of pre-formed steel drums and visual inspection of the quality of the surface finish. It was found that the Marformed components had the smallest range of strain values while the Spinformed components had the largest range.

Key Words: Musical Steel Drum Instrument, Steelpan, Hand-forming, Marforming, Flow-forming, Spinforming

1. Introduction

The Musical Steel Drum, or Steel Pan, is a unique instrument, and one of the most recently invented. It is skillfully hammered from a 55-gallon cylindrical oil drum having a diameter of 57.8cm (22¾ inch), which has been carefully fashioned and tuned to produce musical tones. The Steel Drum carries the full chromatic range of notes, and can be used to produce just about any type of music one desires (Lewis, 1993). The Steel Drum is the newest instrument in the world, having its origins in the late 1930's. In just over half a decade, the Steel Pan musical instrument has spread all over the world, gaining popular ac-

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ceptance as a serious musical instrument (Lewis, 1993). It can be found in reggae bands, rock groups, classical ensembles, jazz combos, and just about any other kind of music one can think of.

There have been a number of books written on the development of the musical steel drum (Blake, 1996; Elder, 1969; Fletcher, 1991; Gay, 1998; Kronman, 1995). This paper presents the historical developments of the steel drum that led up to the instrument as it stands today. It then reviews the manufacturing practices used in the fabrication of the musical steel drum. An experimental investigation was initiated based in the University of the West Indies, Trinidad to examine among hand-forming, spinforming and marforming processes of the steel pan. This paper presents the key findings of the investigation and evaluates various forming processes in order to reduce the time for completion and produce a high quality instrument.

2. Historical Developments of Musical Steel Drum Instrument

In the summer of 1996 a unique collaboration began at the University of Texas at el Paso combining performance and research of the Caribbean Steel drum (Murr *et al.*, 1999). Professors Larry White of the Department of Music and Lawrence Murr of the Department of Metallurgical and Materials Engineering formed the UTEP Performance and Research Teams. The teams realized that there was little investigation done into the metallurgy of this musical instrument and that the musical steel drum was developed purely by trial and error (Murr and White, 2000). The group noted that the acoustical properties of the musical steel drum had been documented by Hansen *et al.* (1995) and thus wanted to link the acoustical properties and metallurgy of the steel drum. They found that the development of the instrument was a complex, non-linear metallurgical process including strain hardening and strain ageing (Murr *et al.*, 1999; Ferreyra *et al.*, 1999). The sinking process had been examined using light metallography (LM) and transmission electron microscopy (TEM) to characterize residual microstructures corresponding to reductions in thickness of up to 50% at the bottom of the drum head. This revealed that deformation had an important effect on the acoustic spectrum, especially harmonic spectra. Harmonic node splitting was observed for thin circular plates and they observed that there was a frequency difference of 60 Hz at 20% cold reduction and 160 Hz at 40% cold reduction. It was noted that these dispersion effects, due to deformation induced microstructures as well as irregularities in the note geometries and thicknesses, point to the complex and non-linear acoustic features that contribute to the sound of the steel drum.

The heat treatment of the steel drum was found to involve strain ageing with the optimum conditions at approximately 350°C for 10 minutes and either water quenching or air-cooling with the ageing effects ranging from 5~20% (Murr *et al.*, 1999). The strain ageing combined with the strain hardening applied to the drum head sinking and note fabrication processes, produces a requisite elastic-plastic interaction which allows for multi-harmonic tuning and the creation of unique chromatic tones and overtones that are characteristic of the various instruments.

Hansen *et al.* (1995) conducted a study on the tuning and mode of the steel drum, and discovered that areas, which undergo significant bending, and displacement exhibit greater pitch changes resulting in changes in stiffness and mass distribution, whereas changes in a region of nodal line will not affect the frequency of that mode significantly. Further to this, the effect of firing the steel drum was investigated (Rossing and Hampton, 1996). After heating, the modal frequencies increased by 10~30%, indicating that the Young's modulus of the steel drum had increased. It was also noted that further working of the metal during tuning partially softens it, but the metal between the notes appeared to remain hard. Some steel drum makers also preferred to harden the surface by heating the drum in either a nitrating bath or in a nitrogen atmosphere. This was desirous since the aim of the manufacturing process was not to create a flexible core for easy tuning but to create a hard surface that resists mechanical deformation when played.

3. The Making of a Steel Pan

Making a steel pan is next to impossible for a beginner. People practice for up to ten years before being able to make a good quality steel pan. People have carried out extensive studies on the tuning of steel pans. In the hand-forming process, the flat surface of a 55-gallon oil drum is sunk using a series of hammers, starting with a 2.7kg (6 lb) sledge hammer and continuing with hammers of decreasing weight until the surface resembles that of a concave bowl. Notes are then marked and grooved out using a dull punch to avoid bursting of the surface.

Typically, eleven steps are identified in the making of a steel pan. These are listed and explained separately as follows:

Step 1 – Choosing the drum

Choosing the correct drum is of great significance towards the final product. Different types of drums are chosen depending on the type of steel pan, whether it is a lead pan, mid-range or bass. The drum being used must be well rounded and free of dents around the bottom of the drum, which will be the area to be worked on.

Step 2 – Finding and marking the centre

Using a flexible ruler one arrives at the centre of the drum. This is done by measuring four equal distances from opposite sides of the circumference. Where the lines intersect is the center. The flexibility of the ruler helps to measure on the concave surface when sinking is in progress.

Step 3 – Sinking the drum

Sinking of the drum generally begins using an eight-pound (8 lb) sledgehammer. As the bottom of the drum gets deeper, lighter hammers are used because the metal gets thinner as it is stretched, so less force will be needed. The process is time consuming and extremely noisy. This can affect the craftsman's hearing if proper steps are not taken to safeguard it.

Step 4 – Counter sinking

The counter-sinking process consists of marking, shaping and preparation for isolating the notes. The notes are sketched out with a marker and then these marks are hammered with a smaller hammer to make the note areas stand out.

Step 5 – Grooving the Steel Pan

The second phase of note isolation is to groove within the dead areas. Grooving the pan is done with a small hammer and a small center punch. At this stage, care must be taken because it is easy to puncture the pan.

Step 6 – Cutting the drum

The type of steel pan determines the length of skirt it will have. The high range pans would have a shorter skirt length so that the notes will "ring out". The bass pans, however, will have the longest skirt.

Step 7 – Cutting the skirt length

After cutting the drum with the chisel, the edge will be rough and uneven. Using a mallet or 1.37kg (3-lb) hammer the skirt edge is straightened and cut with shears to the correct length. Table 1 shows the lengths of skirts for the different types of steel pans.

Table 1. Lengths of skirts for the different types of steel pans

Type of Steelpan	Length of skirt
Tenor	12.7cm (5 inches)
Double Tenor	15.24cm (6 inches)
Double Seconds	22.86cm (9 inches)
Double Guitar	44.50cm (17.5 inches)
Bass	88.90cm (35 inches)

Step 8 – Burning the Steel Pan

After sinking and cutting the pan, the steel must then be tempered to increase the resilience and strength of the metal. A soft steel pan will not stay in tune for long periods.

Step 9 – Tuning tools and instrument.

The pan is placed on a special table called a "tuning table", which consists of sturdy metal legs and a shock-absorbing material on the surface. Other instruments include small hammers, pan sticks of different weights and a strobe, which is a meter used for measuring the pitch of a note.

Step 10 – Tuning the Steel Pan

A hammer is used initially to "bring in the note". The note area is constantly tested with a pan stick while hammering and the note is determined by ear. When all the notes are found by ear, an electrical instrument called a strobe is used to get the accurate tone of the notes.

Step 11 – Blending the Steel Pan

When the pan is finished tuning, it is chromed. Chroming the pan enhances both its aesthetics and tonal quality. The chrome bath detunes the drum slightly, so it must be tuned again after chroming. Each pan can take up to a week of hard work to finish and cost upwards of US$500. Music is produced by striking the notes of the musical steel drum with wooden sticks with strips of rubber rolled at the ends. Figure 1 shows a sketch of a typical Steelpan Musical Instrument mounted on a playing stand, whereas Figures 2a and 2b show the top and front view of the Steelpan, respectively.

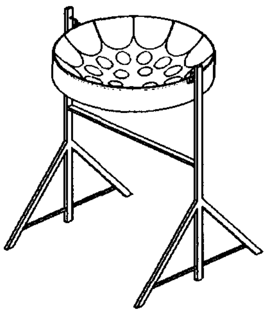

Figure 1. A Steelpan Musical Instrument mounted on a playing stand

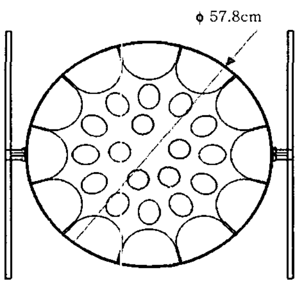

Figure 2a. Top view of a steelpan

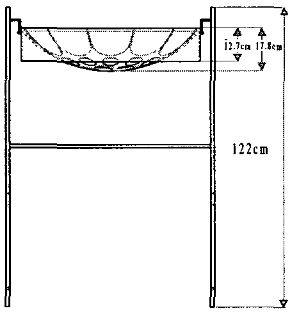

Figure 2b. A front view of the steelpan

4. The Spinforming Process

Spinning is a cold forming method in which a rotating disc of sheet metal is drawn over a male die. The work is carried out on a high-speed lathe except that in place of the tail-stock, the lathe has some means of holding the work against the form. Pressure is added using a round-ended wooden or metal tool. As the metal rotates, the craftsman applies pressure to the disc causing it to flow against the form. In most cases, the metal is kneaded to and fro to give the desired thickness of the form. A considerable amount of skill is required by the operator so a to prevent buckling of the formed piece. Lubricants such as soap, beeswax and linseed oil are use in this process to reduce the friction between the former and work piece. The spinforming process is limited to symmetrical components and most spinning work is done on the outside diameter, although inside work is possible as with the case of the musical steel drum where the material is worked from the center outwards.

Just over 20 years ago, employees of Metal Industries Corporation, Trincity Industrial Estate, Trinidad, and staff members from the Department of Mechanical Engineering at the University of the West Indies got together to develop and refine the idea of making the steel pan using the Spinforming process. They found that too much time was consumed in the sinking of a barrel to make the steel drum. It also entailed a lot of manual painstaking work to groove the notes and at the end of it all, with one bad stroke of the hammer the bowl was rendered useless. The time consuming activities could be eliminated by pre-forming the bowl or dish for the tenor pan using the Spinforming process.

First of all, the metal circular disks, which formed the tops of the oil drums, were obtained to form the bowl of the instrument. These disks were then connected to a high-speed lathe and the whole system was modified to give the required shape. In the initial setup, no backing was used so the disk had to be pushed into shape and checked each time with a tenor pan to observe when the shapes were fairly close. Several problems were encountered, including:

(1) The type of roller was cutting into the pan surface and formed grooves that could not be ironed out to give a smooth surface on the pan.

(2) Cracks were developing in the surface.

(3) There was no backing for the finished product to rest on to give the desired shape.

Using this information together with the results from the first set of pans that failed, a wooden dome was made to the actual profile of the desired end product. The roller used was changed to give the edges a smooth surface. The lever used to push the material was extended to approximately 4 meters and heavy-duty oil was used to lubricate the surface. The changes brought advantages to the process. For instance, pre-formed bowls could be made faster than the hand forming method. There would have a greater control in stretching the pan in Spinforming as compared to the hand forming method.

5. The Marform Process

The Marform process operates using the principle of rubber pad forming techniques. In this type of forming, the die rig employs a rubber pad as one tool half and a solid tool half to form a component into its final shape. The solid tool half is similar to the die in a conventional die set. In this case, it has the concave shape of the steel drum. The Marform process was developed to apply the inexpensive tooling of the Guerin and Verson-Wheelon processes to deep drawing and forming of wrinkle free flanges.

Moreover, the process incorporates the use of a pressure controlled blank holder. In this process, the punch is fixed and the rubber descends on the punch and deforms the sheet metal. The punch has the shape of the dome of the musical steel drum with some notes pre-marked on it. Hence the sheet metal, when deformed, will take the concave shape of the steel drum. This will eliminate the manual sinking process and thus assist the tuner in marking the notes.

Begeman (1963) noted that the Marform process aids in deep drawing of odd shaped parts. The process is superior to the Guerin process since it does not allow the pressure on the blank to build up so as to form wrinkles.

Doyle (1969) stated that the forming pressure usually lies in the range between 34~55 MN/m^2 (5500~8000 psi). Parts that can be produced included flanged cups, spherical domes and many other non-symmetrical shapes. It is more suitable for deep drawing and gives better definition to shallow forming as compared with rubber pad forming. The advantages of using the Marform process include low tooling costs with deep draws of complex shapes and no marring of the surface finish (Morris, 1955).

6. Experimental Investigation

An experimental investigation was recently conducted based on The University of the West Indies, Trinidad. The investigation aimed to examine the hand forming process, Marforming process and the Spinforming process in order to determine the reduction of the manufacturing time and improve the quality of the surface finish of steel pan. Circular metal blanks were divided into twelve sectors and diametral and concentric lines scribed in their surfaces. The thickness strain for each point on the sector was then calculated after the data had been collected. The thickness strain was plotted against the distance from the center for each type of steel drum. Observations and comparisons were then made.

6.1 Sample Results

The percentage (%) of elongation for each point on the sector was then calculated after all the data had been collected (see Table 2). The average % elongation was then plotted against the distance from the center for each type of steel pan, as shown in Figure 3. Observations and comparisons were then made.

Table 2. Thickness strains samples for each forming method

Reading #	% Thickness Strain		
	Handformed	Spinformed	Marformed
1	-5.3	-15.0	-6.2
2	-12.5	-14.1	-9.1
3	-5.0	-12.2	-5.0
4	-2.5	-9.1	-2.7
5	-0.2	-3.0	-0.2

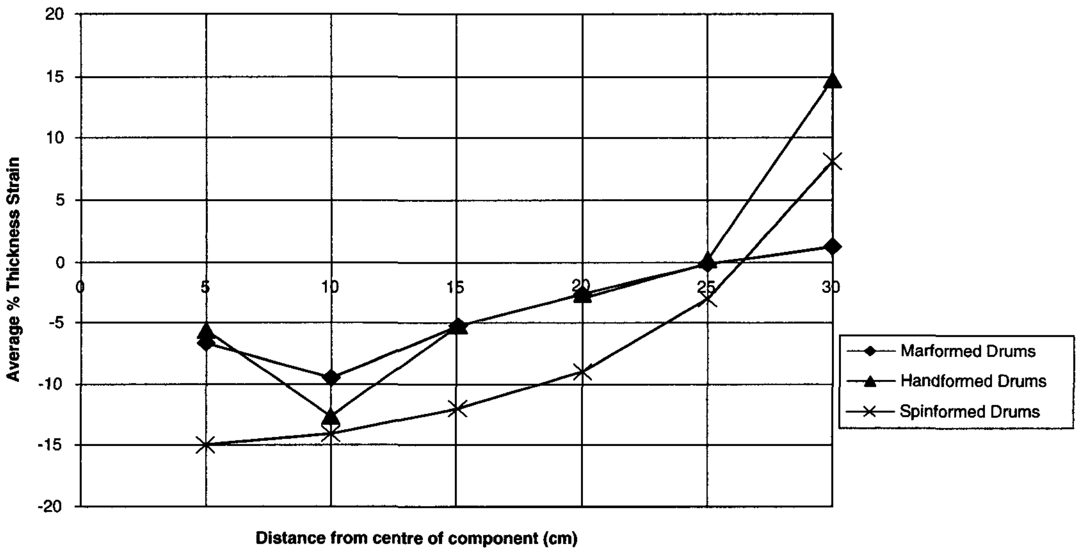

Figure 3. Comparison of Handformed, Marformed and Spinformed Drums

From the analysis of findings, there is a decrease in the strain from the center of the Spinformed component to the perimeter i.e. 5cm from the center to 25cm outwards. The values of the % strain ranged from -15% to 8%. All of the graphs plotted followed a similar general trend. There was a large decrease in % strain from 20 cm to 25 cm. In this region the graph had the steepest gradient. The largest increase took place in the region where the gradient was the largest.

At about 25cm away from the centre the thickness strains decreased until the outer perimeter of the spinformed pan was almost equal to the thickness of the spinformed piece. As one moved away from the perimeter of the pan towards the center, the thickness of the spinformed piece decreased. The highest thickness strain was attained at the centre of the component. The range of strain values that were attained for the hand formed pans was between -5% and 15%. The type of graph that was attained was very much different to the spinformed one and did not show any general trends.

When analyzing the Marformed graph it was clearly seen that almost all of the values contained a negative % strain. In most cases a -3% strain value was attained at the 20cm mark. From the graph plotted, it was clear to see that there was predominantly negative straining taking place. The values were in the range -6% to 1.2%. This was a very narrow region of strain in which the values attained were situated.

6.2 Discussion

The raw data put forward in the data analysis gave a good visual perspective of the formed specimens. The quality of the surface finish, the size of the formed piece and a host of other factors could now be ascertained. The data collection section was very time consuming due to the amount of preliminary preparation of the specimens before readings could be taken.

From the summary of results obtained, rubber pad forming techniques attained the best uniform thickness over the entire specimen area. The main reason for this is the theory behind the application. The rubber will exert an equal and opposite pressure across the entire blank area when compressed by the punch. This resulted in the blank taking the shape of the punch. Equal force is generated around the whole blank region resulting in a uniform thickness over the entire formed piece.

The spinformed components contained a uniform region in which the thickness was fairly constant. The thickness of the specimen in this case was controlled via the use of a "former" on a supporting shaft. The diameter of the former is crucial to the development of a good spinformed specimen. If the former is too large then it will exert a pressure over a large area at any one point in time. This may lead to the formation of radial "buckle" lines on the surface of the formed piece. These buckled regions are very difficult to remove and in most cases the specimen must be discarded. If however the former is too small the pressure exerted on the blank surface area will be very high. This will cause the ball to become very hot and if the ball remains in contact with the spot for a long period of time there could be "fusion welding" taking place. The small surface area of the ball is not large enough to push the material being formed; in some cases "chattering" of the ball may take place. The most effective results are attained when a balance between the large former and the small former is struck.

Spinforming is a very versatile process in that it allows the operator to control the thickness of the specimen. Depending on the user requirements the operator is capable of making certain regions of the specimen with a larger thickness than others. Spinforming allows the operator to literally move material from one region to another. This moving of material is known as "kneading" of the material.

During this process, the "former" is moved forward and back across the entire specimen repeatedly. The region that has to be thinned is located and the procedure is carried out within this area. This will help to explain the positive and negative strain values attained from the spinformed specimens. The thickness of the specimen cannot be controlled as easily with the rubber pad and hand forming processes.

The production time is dependant upon the size of the component being produced and the amount of intricate sections the specimen contains. The production time for rubber pad forming was approximately 20 seconds to form a single component from a given blank. The bowls that were spinformed took an average of about 10 minutes. The longest production time occurred with the hand formed pans, usually taking a few days.

The setup times for these processes vary. The manual forming method will require the least setup time. The material to be formed is placed on a workbench or some supporting mechanism after which the forming process starts. The setup time for Spinforming is dependant upon the size of the blank being formed. The setup time can vary from 5 to 10 minutes. The rubber pad forming has the longest setup time of the three. This is partly due to the fact that the punch is located on the die rig. The die has to be disassembled before removing the punch and replacing it with a new one. This process can take hours depending upon the complexity of the die.

The failure rate of products is fairly high for both Spinforming and hand forming. If the operator is new at the job then there might be many failures. The failure rate is relatively high due to the fact that the operator has to first gain a reasonable idea about the pressures that have to be applied, the revolutions per minute and the feed rate at which the tool should be engaged. The rate at which the operator is able to learn these parameters will determine the degree of failed products.

In manual forming techniques, there are no strict parameters, which the person must abide by. The failures usually occur as cracks in manual forming processes. These are regions where material can no longer undergo any more deformation and as such, the material fails. In hand forming of the steel drums, most of the cracks occurred in the central region of the pan. This is primarily because of the stretching and deformation of material from the outer regions.

The central region did not contain enough material for further deformation to take place. In some of the spinformed specimens, the cracks were also located around the central region. This indicates that the operator was using the former from the center to the outer region during the forming process. The right procedure is to move five outward strokes and then one inward stroke maintaining the same pressure and feed rate.

Rubber pad forming techniques produced products with a very high quality. The reject rate for this type of forming is low. Initially, there might be problems associated with the formed piece (e.g. the formation of wrinkles). This problem can be overcome by using a higher blank holder pressure. The product will now be free of wrinkles so long as the required pressure is maintained.

7. Conclusion

Data collection proved to be a vital tool to obtain critical data pertaining to the different types of forming processes of the steel pan. The graphical representation gave a better overall perspective of the results obtained. The Spinforming and Marforming processes proved to be good methods of pre-fabricating the steel pan since it enabled wrinkle free products of high quality, fairly low setup times, short production times and long production runs.

The investment capital varies for each of the forming processes. Manual forming techniques require the least capital to engage in production. This might be due to the fact that the forming process only requires the use of simple tools. These may include a hammer, chisel, punch, and other simple hand tools.

The Spinforming technique requires much higher capital than that of the manual method. It usually requires a machine capable of spinning a mandrel at varying speeds. One such machine that can be used is the lathe. The former might be very expensive and in most cases they come in sets depending upon the application required. The Marform process has rather expensive setup costs because it requires the use of a press and die rig. These costs however pay themselves off in the long term.

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