



Critical to Quality Parameters (CTQ's) and Continuous Improvement Strategies in Roll Forming Process

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Abstract - The roll forming process operates by feeding sheet metal through a sequence of rollers, each imparting specific shapes onto the metal. These rollers collaborate to achieve the desired cross-sectional profile. Roll forming is a widely used metal-forming process. Today, roll-formed products have numerous applications, for example, in buildings, aeroplanes, the automotive sector, and furniture and domestic appliances. Due to its consistent nature and ease of replication, roll forming offers an effective method for accurately manufacturing large quantities of metal components. This paper explores the identification of critical quality parameters and the development of continuous improvement strategies to enhance overall roll-forming quality.

***Index Terms** - About four, placed in alphabetical order, keywords or phrases that are separated by commas (e.g., Camera-ready, FIE format, Preparation of papers, Two-column format)—Italic for the label "Index Terms"; otherwise, regular font.*

INTRODUCTION

Rolling is a metal-forming technique in which metal stock passes through one or more pairs of rolls to reduce thickness and ensure uniformity. It is the most widely used forming method, offering high production rates and precise control over the final product. Hot rolling allows greater reduction than cold rolling, yet cold rolling typically achieves a superior surface finish, as noted by several studies (Alejandro Rivera Muñiz, 2007; Shahani et al., 2008; Befekadu Zewdie T. Mariam, 2015; Jordan Keith Ogak, 2013; Bauer et al., 2016). Rolling is employed across a wide range of industries, including manufacturing engineering, military equipment,

shipbuilding, bicycle production, pipe manufacturing, railway car construction, bridge building, boiler container fabrication, automotive industry, factory infrastructure, construction projects, elevator manufacturing, household utensil production, and electrical machinery. Virtually all non-ferrous metals are shaped through rolling into standardised forms for further processing. Roll forming is a highly productive process, and its use continues to increase each year (Halmos [19]). Compared to other metal-forming processes, this process offers the advantage that auxiliary operations, such as punching, welding, and clenching, can be included, enabling the production of profiles ready for direct use.

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Figure: Roll-formed products have many applications in the automotive, building, and domestic appliance sectors.

ROLL FORMING PROCESS

Roll forming is a highly efficient fabrication method for the mass production of long, straight metal products. It can be understood as a continuous bending operation in which metal strips are progressively formed through successive sets of rolls into various profiles (Figure 1). Roll forming can

produce a wide range of profiles with various sections. There are two styles of rolling: hot and cold.

Hot rolling occurs when performed at a temperature above the recrystallisation temperature. Moreover, cold rolling occurs when performed at a temperature below the recrystallisation temperature.

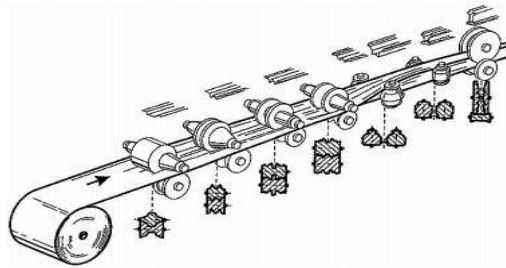


Figure: Roll Forming Process

In roll forming, bending is performed in several steps, beginning with an unreformed strip and culminating in the finished profile (see Figure).

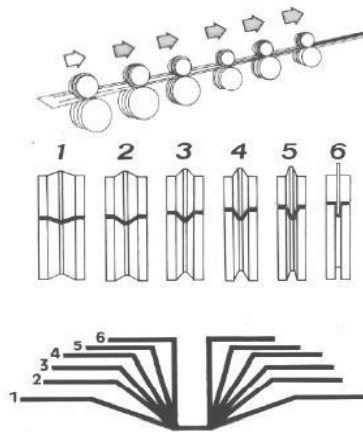


Figure 2.1. The strip is formed in several steps, beginning with an undeformed strip and culminating in the finished profile (Lund et al. [41]).

All materials that can be bent, such as aluminium, steel, stainless steel, and copper, can also be roll-formed, and the material can be pre-painted or pre-coated. The speed at which a profile can be produced varies between 15 m/min and 185 m/min, Tool and Manufacturing Engineers Handbook [3], depending on the tolerance of the cross-section, the material and how fast the machine can be fed with raw material or how fast the finished product can be removed from the run-out table. The thickness of material that can be roll formed ranges from 0.15 mm to 19 mm, Kolev [31]

A TYPICAL ROLL FORMING MILL

A typical roll forming mill is shown in Figure 2.2. It consists of an uncoiler to feed material from a coil

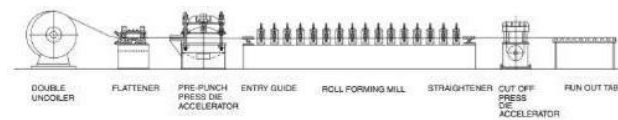


Figure 2.2 Roll forming mill [1]

CRITICAL TO QUALITY PARAMETERS (CTQ'S) IN ROLL FORMING PROCESS

Critical to quality is an attribute of a part, assembly, sub-assembly, product, or process that is literally critical to quality, or, more precisely, has a direct and significant impact on its actual or perceived quality. A CTQ is a measurable characteristic that helps a business achieve a positive outcome from satisfied customers. Both CTQs and CTCs are part of a quality program known as Six Sigma, which uses data and methodology to eliminate defects in any process, from manufacturing to transactional and from product to service.

Critical to Quality (CTQ) parameters in thin-sheet roll forming are the key characteristics or specifications that directly affect the final product's quality. These parameters are crucial because they determine whether the product meets customer requirements and specifications. In the context of thin sheet roll forming, some common CTQ parameters include

1. **Dimensional Accuracy:** This includes the precise measurements and tolerances of the formed sheet. It ensures that the final product meets specified dimensions without deviations that could affect fit, assembly, or functionality.
2. **Surface Finish:** The surface quality of the

continuously during the operation. This is followed by the flattener that levels the material coming out of the coil. After that, a pre-punch press can be placed, which performs pre-punching if needed. Then the material is guided through the entry guide or feeder, which aligns it properly. Next, several roll stands are placed in sequence to bend the material incrementally into the desired shape. After that, the straightener is used to perform minor adjustments to rectify some defects, and finally, a cut-off press cuts the final part to the required length [1].

In the roll-forming process, deformation occurs at each roll station. In the roll former, all bottom shafts are fixed at the same vertical height, and the top shafts are adjustable vertically to adjust for material thickness. The roll gap was set to be the same as the material thickness with feeler gauges.

formed sheet is critical, as it affects aesthetics, corrosion resistance, and, in some cases, functionality (e.g., smoothness for painting or coating applications).

3. **Material Thickness Uniformity:** Ensuring consistent thickness throughout the formed sheet is important for maintaining structural integrity and for subsequent processes such as welding or joining.
4. **Straightness and Flatness:** These parameters ensure that the formed sheet remains straight and flat, which is essential for assembly and fit with other components.
5. **Edge Quality:** The quality of edges after forming impacts the sheet's ability to join with other components and affects the overall appearance and strength of the final product.
6. **Tolerance Control:** This involves controlling the allowable deviation from specified dimensions or other parameters to ensure consistency and compliance with design requirements.
7. **Material Properties:** Parameters such as hardness, strength, ductility, and grain orientation can be critical depending on the application of the formed sheet.
8. **Burr and Defect Control:** Minimising burrs, cracks, wrinkles, or other defects that can affect

functionality or appearance of the final product.

DEFECTS IN ROLL FORMING PROCESS

There are mainly two forms of rolling defects:

A. Surface rolling defects.

B. Internal structural rolling defects.

A. Surface defect: Surface defects occur due to impurities and inclusions at the fabric surface, roll marks, dirt, rust, and other factors associated with previous treatment and handling of metal.

B. Structural Defect: Structural defects are more important rolling defects:

1. Edge defect
2. Alligator cracks
3. Wavy edges
4. Zipper cracks
5. Canter buckling
6. Fold
7. Laminations

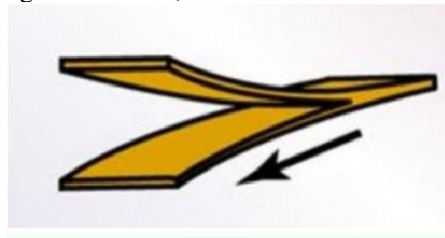
1. Edge defect: During both hot and cold rolling, the metal may exhibit cracks along the edges—this is perceptible due to tensile stresses induced at the workpiece surfaces.



2. Alligator cracks:

During rolling, layers of the metal stock might separate and end within the opening of the slab,

resembling alligator cracks. The artefact adheres to the rolled surface and follows the trail of respective rolls, causing sheets to appear within the plane.

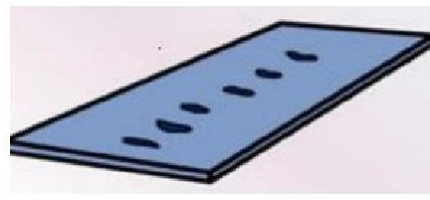


3. Wavy edges:

One of the most common defects in rolling is the occurrence of fibers at the sting, which are longer than those at the centre

4. Zipper cracks:

The occurrence of small cracks within the centre of the metal sheet explains this phenomenon



5. Centre buckling:

This defect occurs due to self-equilibrating residual stresses generated during the rolling process. During centre buckling, the fibre at the centre of the metal piece is longer than those at the side. In a situation where hot or cold mills have an excessive amount of crown, the mills roll out at the centre. Sideways

deflection of a support perfectly explains centre buckling.

6. Fold:

This defect is encountered when the reduction per pass is extremely low.

7. Laminations:

Laminations mean layers. If the ingot is not sound and contains piping or blowholes, and through rolling, they do not fully weld, it will cause a defect called laminations. Fairly often, within the ingot,

there are non-metallic inclusions; during rolling, they will get lengthened along with sound material. This prospect also causes laminations.

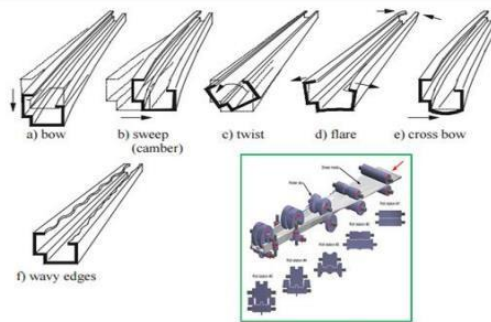


Fig. 1 Defects in Roll forming process (Daya Yesane, 2015)

CONTINUOUS IMPROVEMENT STRATEGIES IN ROLL FORMING

Continuous improvement is the ongoing improvement of products, processes, and services through incremental and radical steps. There are several approaches to continuous improvement in

Roll Forming. Each system has unique aspects and different emphases. However, all share the same basic assumptions: an organisation has limited capital and management time, and these resources should be put to the very best use to optimise productivity and quality. Improvement efforts are cyclical and never-ending.

Sr No	Continuous Improvement Strategies	Description
1	Deming cycle	<p>Walter Shewhart originally conceived the Deming cycle in the 1930s. The approach involves the following steps:</p> <p>Plan – Examine the current situation, gather data, identify problems, and develop solutions.</p> <p>Do – Test out the plans on a trial basis (minimizing disruption) and collect resulting data.</p> <p>Study/Check – Determine whether or not the plan achieved the desired results. Modify the plan if needed.</p> <p>Act – Implement the plan throughout the organization.</p>

2	DMAIC	<p>The American Society for Quality defines DMAIC as “a data-driven quality strategy for improving processes and an integral part of a Six Sigma quality initiative.” [2]</p> <p>DMAIC is an acronym for the following steps:</p> <p>Define – Clearly define the problem to be solved. Define the current state as well as the expected results after the improvement project.</p> <p>Measure – Define the questions to be answered, what form the answers will be in, where the data will come from, and how to collect the information</p>
		<p>with minimal effort and lowest chance of errors.</p> <p>Analyze – Focus on why defects or errors occur. Identify the root causes of the problem. Conduct experiments to confirm hypotheses in a statistically valid form.</p> <p>Improve – Generate multiple solutions via brainstorming. Evaluate each idea and select the most promising solution. Confirm the success of the solution relative to the expected results; refine if necessary.</p> <p>Control – Put a system in place to maintain the results. Establish necessary policies, procedures, and training. Develop controls to ensure that key variables remain within the acceptable range.</p>

3	FADE	<p>The FADE model is similar to the Deming and DMAIC systems and is widely used in healthcare and many branches of the government. FADE stands for:</p> <p>Focus – Select a problem to be addressed, characterize the current process, show why a change is necessary, and describe the desired end result and the benefits of the change.</p> <p>Analyze – Describe the process in greater detail, identify root causes, and determine which information is necessary.</p> <p>Develop – Create a solution and implementation plan with financial justification.</p> <p>Execute – Implement the solution and establish a monitoring plan.</p>
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MEASURING PERFORMANCE OF ROLL FORMING PROCESS

1. OEE and TEEP: Overall Equipment Effectiveness (OEE) is a measurement of how effectively a machine is operating during the time it is scheduled to run. OEE is used as a primary performance metric and was developed as part of the Total Productive Maintenance (TPM) process. There are three main components of

OEE:

Availability – The ratio of machine run time to the scheduled production time.

Speed – The ratio of actual running speed to the machines maximum speed.

Yield – The ratio of good material produced to the total material used

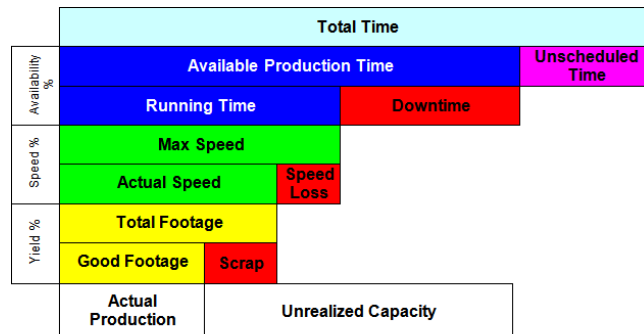


Figure 2 - Components of OEE

Each component is expressed as a percentage, and the product of all three equals the OEE value. A 100%

shift OEE would require a machine to run an entire shift (excluding break times) with no downtime, at

the maximum rated speed, and with no scrap. Although there may be single-profile tube mills with coil accumulators that approach 100% OEE, most roll formers run between 20% and 65% OEE.

It is important to note that unscheduled time is not considered in the availability percentage. Unscheduled or exempt time includes all break times,

meetings, planned maintenance, training time, and other intentional breaks in production. These downtimes do not affect the OEE metric. They do, however, affect the Total Effective Equipment Performance (TEEP) calculation.

The three components of OEE: availability, speed, and yield, can be further broken into sub-categories:

Availability Losses	Speed Losses	Yield Losses
Setup Time Equipment Failures	Reduced Speed Minor Stoppages	Startup Scrap Defects

TEEP

Total Effective Equipment Performance, or TEEP, is very similar to the OEE metric, except it considers the total clock or calendar time available to run production, rather than just the scheduled production time. For an operation that runs two eight-hour shifts, the OEE metric considers only the 16 hours minus scheduled downtimes as available production time. TEEP includes all 24 hours and provides a more direct measure of the equipment's possible capacity.

$$\text{TEEP \%} = \text{Asset Utilization \%} \times \text{Speed \%} \times \text{Yield \%}$$

$$\text{Asset Utilization \%} = (\text{Run Time})/(\text{Total Time}) = (153 \text{ min})/(1440 \text{ min}) = 11\%$$

$$\text{Speed \%} = (\text{Actual Rate})/(\text{Max Rate}) = (483 \text{ fpm})/(525 \text{ fpm}) = 92\%$$

$$\text{Yield \%} = (\text{Good Footage})/(\text{Total Footage}) = (73,784 \text{ ft})/(74,000 \text{ ft}) = 99\%$$

$$\text{TEEP \%} = 0.11 \times 0.92 \times 0.99 = 10\%$$

ANALYSIS TOOLS

There are several methods available to help determine where to focus improvement efforts and spending best.

The Five Why Method

The Five Whys technique is a useful way to determine the root cause of a particular problem. Rather than stopping at the first cause of a defect or problem, the reason for that cause is questioned through successive research into each cause and its reasons, until the root cause is discovered. It is not necessary to stop after exactly five "whys" have been asked; the questions should continue until the underlying cause is discovered.

For example, a roll former with a post-cut shear failed, sending material up into the rafters. Why did the material buckle up? Because it jammed in the shear die during the cut. Why did the material jam in the shear die? Because the die was dull. Why was the die dull? Because it missed the last sharpening rotation. Why did it miss the rotation? Because of poor record-keeping. The process continues for as many whys as needed to reach the root cause.

Cause and Effect Diagrams

When investigating production problems, it is important to analyse the various causes of a particular effect. Fishbone (Ishikawa) diagrams can be used to identify the various causes and contributing issues. While these diagrams do not necessarily indicate the relative magnitudes of the causes, they do help limit the scope of subsequent data collection efforts.

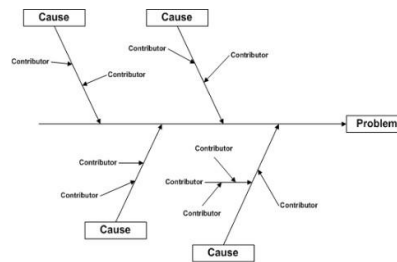


Figure 5 - Fishbone Diagram

A Pareto chart is a histogram of items sorted by descending frequency. It often shows that a high percentage of problems (downtime, slowdowns, and defects) are caused by only a few issues. Concentrating efforts on the left-most issues will yield the most dramatic results for the time and money invested.

The Figure shows a portion of a Pareto chart of

downtime reasons for a single machine for a month of production. The height of the bar indicates the percentage of total downtime for each delay reason. It can also be helpful to include a plot of cumulative percentages. This shows that the top few issues account for a significant share of the total problems. For example, Figure 6 shows that approximately 75% of the total downtime was due to profile or coil changes.

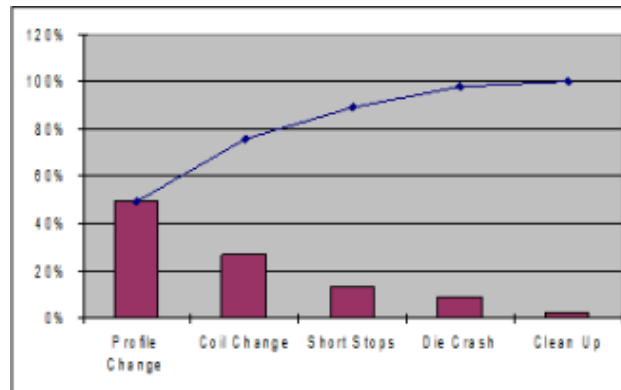


Figure 6 - Pareto Chart

SPC Tools

Although a full discussion of statistical process control (SPC) falls outside the scope of this document, it may be useful to consider two aspects of

SPC when dealing with defect rates in a process. It is important to determine whether the equipment in question can reliably produce within the required tolerance and whether the process is in control.

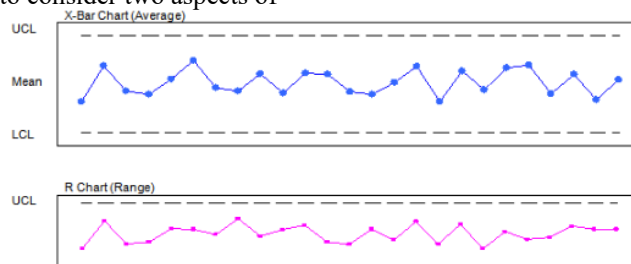


Figure 7 - Control Charts

IMPROVEMENT TECHNIQUES

Once problem areas are identified, the next step is to work to address them. While processes such as kaizen blitzes support general problem-solving, two techniques specifically address reducing downtime and improving quality.

Single Minute Exchange of Die (SMED)

Shigeo Shingo developed SMED as part of the Toyota Production System. It was designed to take machine changeovers that used to last up to several hours and improve them so they could be accomplished in less than ten minutes. Steps in a changeover can be separated into two categories:

operations that can only be done with the machine stopped (internal) and those that can be performed off-line while the machine is still running (external). Recognising the difference is critical.

The following are the three major stages of the SMED system:

Determine exactly which steps are internal or external, and ensure that only internal operations occur when the machine is stopped.

Find ways to convert internal activities to external activities. Streamline all activities to reduce the changeover time. This may include involving additional staff working in parallel. The use of quick-

release clamps and machine automation can help in this stage.

For a roll former with a single-mandrel uncoiler, a few activities can be done in the first stage of SMED, such as preparing the new coil so it is in proximity to the uncoiler before the change. An upgrade to a double-mandrel uncoiler shifts the loading and unloading of the coil to external steps. The only internal steps remaining involved switching the uncoiler sides and threading the new coil. The addition of a coil accumulator eliminates all internal steps, since the new coil is loaded and butt-welded to the previous coil while the machine is still running (the accumulator gives the operator a few minutes to complete the joining operation).

The use of rafted mills or duplex mills is another example of shifting from internal to external steps when changing profiles.

Zero Quality Control (ZQC)

Rather than spending time trying to catch defects or mistakes after they occur, ZQC encourages foolproof prevention. This involves 100% inspections of parts at each step (an automatic check if possible), immediate feedback if problems occur, and the use of "poka-yoke" systems wherever appropriate.

The poka-yoke approach typically involves the use of simple sensors or jigs to either let the operator know immediately if something has been forgotten or improperly installed or to prevent mistakes from occurring in the first place. A simple example of this would be designing an electrical connector that can be plugged in only one way (the correct way).

Conclusion

There are several ways to translate increased knowledge, productivity, and quality into financial gains.

By using OEE and other analysis tools, manufacturers can optimise capital spending. In some cases, this may mean upgrades of uncoilers, mills, or press systems to improve areas that were restricting productivity. In other cases, it may still be necessary to purchase new machines, but these purchases can be made with knowledge of which features really aid effective production. Efficiency improvements can reduce labour costs for the same output. In situations where sales volume is fixed, reductions can be made in the number of shifts or in the overtime hours required. The newly created free time can also be spent improving machine reliability through autonomous maintenance or on other improvement

projects.

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