# Chapter 4.8
# STRAIGHTENING FUNDAMENTALS

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## INTRODUCTION

Becoming a world-class manufacturer of components for the metal working industry requires an ever increasing focus on improving quality and controlling the manufacturing process. Six Sigma and ever higher CpK requirements demand a manufacturing process that reduces waste and increases the statistical process controls and traceability of parts throughout the system. Straightening can provide that process control and improve the quality of the parts by automating that function. This section will focus on these improvements both in the part and in the pre and post processing of that part.

## CAUSES OF DISTORTION

The need to straighten parts results from distortions caused by the manufacturing processes specific to these parts. They can include processes such as:

- Forming processes such as extrusion or upsetting. Parts such as axle shafts and pinions which are formed in this manner distort due to the extreme forces placed on the part. Worn or misaligned tooling can further exacerbate the problem.
- Cut to length operations can result in distortions at the ends of parts if cut off tooling wears, material quality varies, or if fixturing devices fail.
- Material handling or improper storage of parts can lead to distortion.
- Heat treatment is a significant cause of distortion in parts. This is especially true if the part quenching process is not well maintained. The reason that parts distort in heat treatment is the differential cooling rates for different cross sections of the workpiece.

Typical parts that require straightening due to these factors include:

- Transmission shafts and drivetrain components such as pinions
- Axle shafts
- Camshafts and Crankshafts
- Steering components such as steering racks and steering pinions
- Pumpshafts and compressor shafts
- Electric motors and armature shafts

## JUSTIFICATIONS FOR USING A STRAIGHTENING OPERATION

To compensate for this distortion, the manufacturer can either use starting material with sufficient excess stock that it can be removed to meet part process tolerances or he can choose to straighten the part. The advantage of straightening is clear:

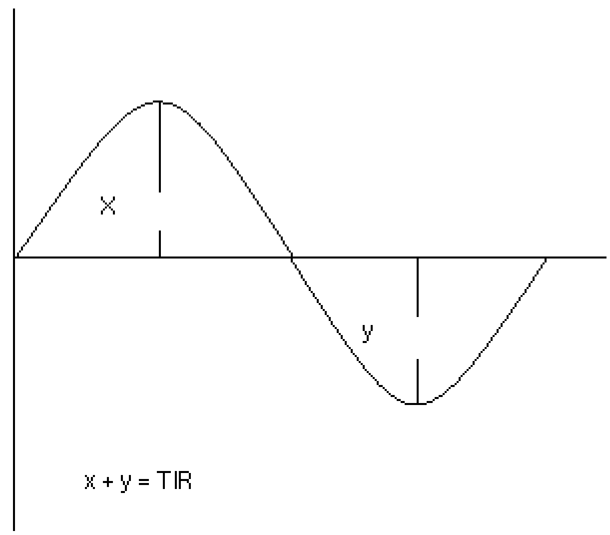
- You save material costs by buying starting material that is closer to the near net shape of the part.
- You reduce the amount of grinding or turning required by straightening to a closer tolerance. Straightening is always less expensive than a material removal process as it requires no abrasives or cutting tools and it does not require coolant. The straightening process is also faster than a metal removal process and will increase the production throughput. The cost of the equipment is also less as one straightener can replace the need for multiple grinders to meet the required throughput.
- The quality of heat treated parts improve considerably due to more uniform case depth hardness. If a part is not straightened before grinding, it will have more stock removed on the high side than the low side resulting in a shallow case depth on one side of the part.

Given these facts, it is clear that straightening can result in a better part and it is a more economical and productive process than existing material removal processes. It also stands to reason that the closer tolerance you can achieve in straightening will result in even greater cost savings and even better part quality. The obstacle to this in the past was that straightening was a manual process and the manufacturer was dependent on the operator to determine with manual gauging whether the part was within tolerance or not. As a result, acceptable tolerances were typically in the range of about 0.1 mm TIR (Total Indicator Runout – or the total difference measured between the high and low point of the workpiece in one full rotation of the workpiece on its linear axis). Straightening times were also a function of the skill of the operator and could fluctuate greatly.

**THE STRAIGHTENING PROCESS**

The straightening process begins with the determination of what constitutes a good part and how this can be measured. Straightness is a linear measurement that determines the deviation from a theoretical centerline of the workpiece measured from one end of the part to the other. Since this poses difficulties in fixturing and measuring the part in a production process, straightening measurements are determined by measuring TIR (Total Indicated Runout) at critical surfaces along the linear axis of the workpiece. TIR is measured by placing a transducer under the part at that critical surface and rotating the part 360 degrees. This results in a sinus curve depicting the high and low point of the measurement.

**Figure 1**




Knowing the high and low point of the deflection at each straightening point enables the control to determine the theoretical centerline of the workpiece. The centerline is equal to exactly one half of the Total Indicated Runout.

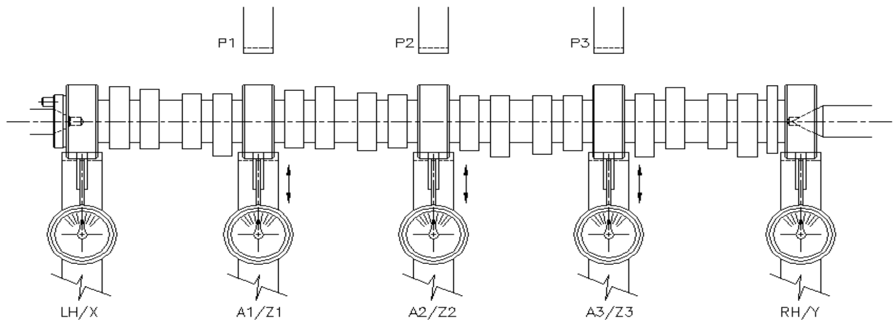
An automatic straightening machine uses a servo driven center tool or roller device for rotating the part 360 degrees. The servo drive has a pulse counter that takes about 200 measurements for each full revolution of the part and records the measurement data from the transducer at each of these points. With the high speed PC controls available on the market, most machines can measure and store this data for up to seven different straightening points along the workpiece in as short a time as 0.5 seconds.

It is critical when determining the straightening locations to also consider the base datum for these measurements. The choice of straightening locations and the base datum are made based on the functionality of the part as well as the manufacturing processes employed. Some of these considerations are as follows:

- The straightening points should include bearing surfaces so as to remove the possibility of vibration in the parts ultimate application.
- The straightening points should include surface areas that come into contact with opposing parts in the final assembly. For example, matching gear sets should provide for measuring and straightening within the pitch diameter of the gear.
- Base datum for measuring TIR should either be the OD of the part or the centers of the part. If all future manufacturing processes are done between centers, the straightening should be done relative to the centers. If the part is to be ground in a centerless grinder after straightening, the base datum should be the OD of the part.

At this point of the automatic straightening cycle, the part has been transferred into the straightening station of the machine, clamped between centers or on rollers, rotated 360 degrees and measurements have been taken at all the straightening points relative to the base datum. For each straightening point, the machine control has recorded the TIR along with the angular displacement of the high and low point of the deflection. The straightening process can now follow either a predetermined straightening sequence or, as is more common, start straightening at the point with the greatest deflection.

**Figure 2**




In the above example, a camshaft has been clamped between two male centers and TIR measurements have been taken at surfaces Z1, Z2, and Z3 relative to the base datum at X and Y. Assuming that the deflection is greater at Z2 than at Z1 or Z3, the machine would start at Z2. The process is as follows:

1. The servo driven center rotates the part so that the high point at Z2 is located directly underneath Punch 2. As the acceptable tolerance has been set for this straightening point, a value equal to one half of the final TIR is determined to be the straightening target. For example:
   a. Initial TIR is .100 mm
   b. Required straightening tolerance is .030 mm
   c. Target tolerance is .015 mm or ½ of .030 mm TIR. In reality, the target is set slightly below ½ of the acceptable TIR so that on the final revolution, the part is well within the required TIR tolerance. In this case the target would be .013 or .014 mm.
2. The straightening ram advances a length that is calculated based on the distance between the ram starting point, the part surface and the measured deflection. Most straightening systems on the market automatically adjust the stroke based on the measured deflection so that the part can be straightened with the fewest possible stokes.
3. The ram holds the part briefly at the maximum bending moment than retracts to a position just above the part. The transducer than records its present position relative to the target tolerance. If the target of .013 mm has been reached, the part will be rotated one time to confirm that the TIR is within the allowable tolerance.
4. If the part has not reached its target tolerance, the stroke will be adjusted once again by the remaining deflection and the ram will stroke again. This will continue as necessary till the part is within tolerance at Z2.
5. Once Z2 is within tolerance, the same process is repeated at Z1 and Z3 or at as many straightening points as required until the part is within tolerance.
6. After the last straightening point is within tolerance, the part is rotated once again and all surfaces are measured to confirm that the part is within tolerance over its entire length.
7. If the part is within tolerance it is picked up and transported through the machine to the unload conveyor. If the part could not be straightened within a preset time limit or if the part was determined to be cracked, the part is rejected and will be separated into a reject unload station.

**ADDITIONAL FEATURES AVAILABLE IN THE STRAIGHTENING PROCESS**

The previous section explained the process of measuring the straightness of the part and the process by which the part is flex straightened to the required tolerance. In addition to this process, various other methods can be used to improve the quality of the part and to meet the required tolerance within an acceptable production rate. A brief description of these methods follows:

- For through hardened workpieces that cannot be flex straightened due to the danger of part breakage, peen straightening can be used. In this process, the part is positioned with its low point under the ram and the ram strikes the part with a quick blow at the required straightening point. This process leaves a mark on the workpiece but it results in the release of stress at that point and the part “growing” in the direction from which it is hit. Because the ram does not bend the part, it does not cross the tensile threshold thus not breaking the part. This process is suitable for brittle parts such as cast iron camshafts where the peen force is applied to the surface areas between the bearing and lobe surfaces of the camshaft. It is not suitable for high tolerance straightening and the best possible TIRs are in the range of 0.10 mm.
- For parts in the green before heat treatment, roller straightening can be used for straightening and stress relieving. This is often used for extruded axle shafts that are roll straightened after extrusion but before cutoff and centering operations. Roll straightening involves clamping the part in a chuck and rotating it while bending it under rollers to a certain deflection. By controlling the length of stroke, the speed of rotation and the hold down time under pressure, parts can be straightened to tolerances between 0.5 and 1.0 mm TIR.
- Crack detection can be incorporated into the straightening process using devices such as acoustic emission, eddy current and ultrasonic crack detectors. These can be installed in the straightening station or in the unload conveyor to provide for 100 % inspection. Parts that are cracked will be rejected and a separate counter will keep track of that number independently of any other rejected parts.
- Measurements of the center runout relative to the OD of the part can be taken and parts can be rejected if the center runout exceeds an allowable amount.
- Using an algorithm known as FFT (Fast Fourier Transform) parts with rough surfaces can be measured and a theoretical centerline can be determined. This measurement than is a true measurement of the deflection of the part independent of errors in the geometry of the part or surface condition of the part. This is necessary for straightening parts such as:
    - tubing that might be out of round
    - hardened parts with heat treat scale
    - hexagonal or square shafts
    - gears that have form error greater than the allowable straightening tolerance
- Using master gears attached to the measuring transducers, the pitch diameter of gear surfaces can be measured. This ensures that the runout at the meshing point of matching gear sets are within tolerance. By using the FFT described above, one can also measure the difference between the TIR of the part on the pitch surface with the filter on or off. This results in measuring the form error of the part independent of the deflection of the part. Parts whose form error relative to deflection is greater than an allowable tolerance can than be rejected.
- Most automatic straightening presses available now offer PC controls that provide for connection via Serial link or better still by Ethernet to a factory information system. This provides for real time data tracking of the manufacturing process. All incoming measurements, cycle times, reject rates and types, and final measurements can be transmitted to a factory information system to be used to analyze and improve the process.

**SELECTING THE PROPER EQUIPMENT**

Traditionally, straightening has been done utilizing hydraulic presses due to the infinitely adjustable stroke length and the ability to adjust pressure necessary to overcome the resistance of the workpiece. Lately, there have been advances in mechanical drives that provide for easy adjustment of the stroke length. These electro-mechanical presses offer the following advantages to the traditional hydraulic drives as follows:

- Smaller footprint because no hydraulic power units are required
- Less energy consumption.
- Better environmental considerations
- Lower maintenance requirements

Hydraulic presses though still have the advantage in applications requiring longer stroke lengths such as parts with a high initial runout and / or a high degree of elasticity. Apart from the decision as to whether to choose a mechanical or hydraulic drive, a more important consideration is the degree of automation desired. This decision should be made based on the following considerations:

- Are parts going to be processed in large lot sizes or in small batches?
- Do the parts to be straightened fit into family groups that allow for automatic changeover?
- Will the straightening equipment be installed in a production line or in a manufacturing cell?
- How close do you need to straighten?
- What are the financial resources available for investment?

There are presses available on the market for manual straightening, semi-automatic straightening, and fully automatic straightening. A brief analysis of their competitive advantages is as follows:

| | **MANUAL** | **SEMI-AUTOMATIC** | **AUTOMATIC** |
|---|---|---|---|
| **PROS** | Inexpensive | Automated straightening sequence – 100 % inspection | Fastest cycle times |
| | Easy Changeover | Low maintenance | Fits into automatic production lines. |
| | Easy to operate | Easy changeover | Small footprint |
| | Ideal for cells | | |
| **CONS** | Accuracy depends on operator | Not as fast as a fully automatic machine | Most expensive |
| | Slower cycle time | Part travels as opposed to straightening tooling | More involved tool changeover for different family of parts |

Due to the many offerings available on the market, it is suggested that a full investigation be completed before selecting the proper equipment for your application. If possible, straightening tests are advisable to determine actual production rates based on your particular part characteristics.