«Troubleshooting common tube bending issues – a material guide»

Learn about tube bending, its history, the most common problems encountered in tube bending, and how aluminum bronze can help solve these problems.

TECHNICAL PAPER

Tube bending has evolved from basic manual techniques used by ancient craftsmen to advanced methods driven by technological innovations. This technical paper explores the historical roots and modern advancements in tube bending, highlighting the journey from traditional practices to the latest innovations shaping the industry today. From the beginning of CNC machines to the integration of robotics and AI, tube bending continues to evolve, driven by the need for precision, efficiency, and sustainability. AMPCO METAL has played a critical role by providing superior alloys – such as AMPCO® 18, AMPCO® 18.23, AMPCO® 21, AMPCO® 25, and AMPCO® M4 – that enhance the performance and durability of tube bending applications. The primary objective of this technical paper is to provide a comprehensive guide to troubleshooting common tube bending problems, highlighting the critical role of materials such as AMPCO® alloys in overcoming these challenges.

History of tube bending

The process of tube bending has undergone a remarkable transformation in recent times. Once a traditional craft requiring extensive trial and error, it has been revolutionized by technological advancements and innovative approaches. Over time, the industry has witnessed a shift towards automation, precision, and efficiency, which has revolutionized the way tubes are formed.

In the early days of tube bending, the craft was predominantly manual, relying on the expertise of craftsmen to achieve desired bends through trial and error. While this method was effective, it often resulted in material wastage and prolonged production timelines as craftsmen experimented with different parameters to achieve accurate bends.

CMM integration and all-electric machines

To address challenges such as springback and ensure dimensional accuracy, the integration of Coordinate Measuring Machines (CMM) with tube bending machines have emerged as a critical innovation. Manufacturers nowadays utilize CMM data to validate bending parameters, enabling precise adjustments without the necessity for trial and error. This integration not only enhances accuracy but also reduces material wastage and enhances productivity.

The integration of automation and Computer Numerical Control (CNC) technology has been a significant advancement in modern tube bending. In the present era, leading machine manufacturers have developed comprehensive tube bending cells that feature automated weld seam detection, internal lubrication systems, and robotic loading and unloading capabilities. These advancements significantly enhance productivity by minimizing manual interventions and optimizing machine performance.

In contrast to traditional hydraulic machines, all-electric models offer unparalleled precision with an accuracy of less than 0.05mm. They also provide repeatability, resulting in consistent bend quality and reduced scrap rates. Furthermore, these machines facilitate rapid reprogramming and eliminate manual adjustments during production changeovers, enhancing flexibility and efficiency.

The path forward

The necessity for innovative solutions in the context of complex geometries and varying bend radii is obvious. Multistack bending machines, which feature multiple sets of tooling, are an example of such a solution. These machines facilitate seamless transitions between different radii without manual intervention, thereby streamlining production and minimizing setup time.

The recent use of simulation software has rendered it an indispensable tool for modern tube bending operations. By simulating the bending process, manufacturers can identify potential collisions and optimize bending sequences to minimize cycle times. This not only enhances productivity but also ensures equipment and tooling integrity, reducing downtime and material wastage.

As tube bending technologies continue to evolve, driven by automation, precision engineering, and simulation capabilities, the industry is poised for further advancements. These innovations enhance efficiency and quality control while also contributing to sustainable manufacturing practices by minimizing waste and maximizing resource utilization.

The subsequent chapters of this technical paper will examine in greater depth the techniques employed to overcome the common difficulties encountered in tube bending. The role of materials such as AMPCO® alloys will be considered in detail, with particular attention paid to their ability to facilitate the resolution of challenges and the optimization of performance in modern tube bending applications.

Troubleshooting common tube bending issues

Tube bending presents a range of challenges that can impact the quality and integrity of bent components. This chapter focuses on troubleshooting these issues and provides practical solutions to address common problems encountered during tube bending processes.

Wrinkling

Wrinkling throughout the bend can be a persistent issue, often occurring up to the bend die zone. To address this, advance the wiper die closer to the tangent and decrease the rake angle of the wiper die. Additionally, re-cutting any worn wiper dies and ensuring that the tooling used is of high quality can help improve the process. Increasing the pressure of the pressure die can also mitigate wrinkling in this area. When wrinkling occurs in only a portion of the bend, it is important to check the roundness of the bend die and address any taper present in the pressure die. Adjusting the rake angle of the wiper die and evaluating the overall quality of the tooling can also prove beneficial in reducing partial wrinkling.

If wrinkling is observed throughout the entire bend zone even with the wiper and mandrel in position, verify that the mandrel is the correct size and ensure the proper fit and location of the wiper. Reducing the force on the pressure die advance may also be necessary. Additionally, a thorough examination of the tooling quality should be conducted to identify and rectify any issues contributing to the wrinkling.

Heavy wrinkles in the bend area, along with linear scratches in the clamp area, can be attributed to several factors. To mitigate these issues, start by reducing the pressure die force. It is also crucial to verify the positions of the mandrel and wiper die to ensure they are correctly aligned. Adequate lubrication is essential in preventing these defects, so ensure that lubrication is applied properly. Using serrated or carbide spray in the tube groove of the clamp die can also help. Finally, as mentioned above a thorough evaluation of the tooling quality is necessary to identify and resolve any contributing factors.

Excessive collapse, whether accompanied by wrinkling or not, requires careful troubleshooting. Begin by adjusting the mandrel towards the point of tangency to provide better support during the bending process. Adding more balls to the mandrel can also help in achieving a smoother bend with fewer defects. As always, evaluating the quality of the tooling is critical to ensure that it is not contributing to the problem. High-quality tooling can make a significant difference in achieving the desired bend without excessive collapse or wrinkling.

Outer wall thinning

Outer wall thinning during the tube bending process can arise from various issues. To address this, begin by reducing the force exerted by the pressure and clamp dies. This reduction helps to minimize the excessive pressure that contributes to wall thinning. Additionally, address any friction caused by improper clearance between the mandrel and the tube's interior. Ensuring the correct mandrel clearance is crucial to prevent undue stress on the tube walls. Finally, check the travel speed setting of the pressure die assist, as improper settings can exacerbate thinning. Adjusting these factors can significantly mitigate outer wall thinning and improve the quality of the bend.

Tearing of tube

Tearing of the tube during bending can be resolved by following several key steps. First, check the alignment of the mandrel to ensure it is positioned correctly within the tube. Proper alignment is essential to avoid undue stress that can lead to tearing. Additionally, ensure that the tube material has the proper elongation properties to withstand bending without fracturing. Consider the characteristics of the tube material, such as its hardness, as materials that are too hard or brittle are more prone to tearing. Evaluate the travel setting of the pressure die assist to ensure it is correctly adjusted, as improper settings can contribute to material tearing. Lastly, address any friction-related issues by ensuring adequate lubrication and proper clearance between the tube and tooling to minimize friction during the bending process.

Ovality

Ovality or flattening of tubes during bending can be mitigated by taking several troubleshooting actions. Start by setting the mandrel position correctly relative to the tangent to provide optimal support during bending. Reduce the clearance between the pipe's inner diameter (ID) and the mandrel's outer diameter (OD) to ensure a tighter fit, which helps maintain the tube's shape. Check the travel setting of the pressure die assist slide, as incorrect settings can exacerbate ovality and flattening. Address any slippage in the clamp to ensure the tube is held securely throughout the bending process. Finally, verify the mandrel configuration, specifically the number of balls, to ensure it is appropriate for the bend and provides adequate support to prevent deformation.

Humps on bent tube

To eliminate humps in tube bending, several steps can be taken. First, adjust the mandrel assembly to ensure it is positioned correctly and provides the necessary support during bending. Evaluate the characteristics of the tube material, as some materials may be more prone to developing humps. Check the machine features that affect mandrel withdrawal, ensuring they are functioning properly and not contributing to the issue. Finally, increasing the force on the pressure die assist provides better support and control during the bending process, which can help eliminate the formation of humps. To resolve issues with humps at the end of the bend, adjust the mandrel position slightly to optimize support during the bending process. Furthermore, by increasing the force on the pressure die assist, better control and stability during bending are achieved.

Tool mark

To address tool marks on the bend centerline during tube bending, follow these troubleshooting steps. First, re-adjust the alignment of the clamp and pressure die to ensure they are properly aligned with the bend centerline. Check the dimensions of the tooling to ensure they are suitable for the tube size and shape being bent. Evaluate the tube size and fit within the tooling, making any necessary adjustments to prevent contact that could cause tool marks. Finally, ensure proper lubrication is applied to minimize friction and prevent the tooling from marking the bend centerline of the tube. Taking these steps can help achieve clean bends without visible tool marks.

Excessive springback

To mitigate excessive springback in tube bending, follow these action steps. First, ensure that the pressure die does not hinder the movement of the tube during bending, as excessive pressure can contribute to springback. Assess the properties of the tube material, including its ductility and elasticity, to understand its behavior during bending. Adjust the bending program to compensate for springback by overbending slightly to account for the material's tendency to return to its original shape. Implementing these measures can help minimize excessive springback and achieve the desired bend geometry more accurately.

Mandrel breakage

Preventing repeated mandrel breakage during tube bending requires a strategic approach. First, increase the mandrel clearance to reduce stress on the mandrel during bending. Address any weld flash or debris inside the tube that could contribute to mandrel breakage. It's essential to ensure that the tube is clean and free from contaminants that could affect the bending process. Lastly, evaluate the suitability of the mandrel design for the specific bending application to ensure it can withstand the bending forces without breaking. By implementing these measures, you can prevent mandrel breakage and ensure smooth tube bending operations.

Deep scratches

To address deep scratches throughout the bend and wiper die zone in tube bending, several potential fixes can be implemented. Begin by increasing the wiper die rake to improve contact and reduce scratching. Verify the size and position of the mandrel to ensure proper support and alignment during bending. Adjust the pressure die force to optimize the bending process and minimize scratching. Additionally, ensure adequate lubrication is applied to reduce friction and prevent scratching throughout the bending operation. By implementing these fixes, you can improve the overall quality of tube bends and minimize deep scratches in critical areas.

Inconsistency

To address inconsistency from part to part in tube bending, a comprehensive troubleshooting approach is essential. Begin by addressing clamp slippage to ensure secure positioning of the tube during bending. Evaluate the elongation characteristics of the tube material to understand its behavior and adjust accordingly. Additionally, review and adjust pressure die settings to optimize the bending process for consistency. Finally, closely examine machine behavior and operation to identify any factors contributing to variations between parts. By systematically addressing these aspects, you can minimize inconsistencies and achieve more uniform results in tube bending operations.

How AMPCO® material helps troubleshooting common tube bending issues

AMPCO® material is used to prevent scratch marks and seizing. Generally, AMPCO® alloys are used in the tube bending process for wiper dies and mandrels (wiper die and mandrel are parts of tube bending tooling).

How AMPCO® material helps to eliminate scratch marks on the tube: AMPCO® 18, AMPCO® 18.23, AMPCO® 21, and AMPCO® M4 play an important role in the tube bending process by preventing scratch marks due to their high-quality surface finish, good sliding properties, and low coefficient of friction.

In the context of the tube bending process, the high-quality surface finish and good sliding properties of AMPCO® material allow the tube to slide smoothly along the bending tools such as the wiper die and mandrel, resulting in less resistance. The low coefficient of friction ensures smoother movement, reducing the occurrence of scratches.

Additionally, AMPCO® alloys prevent galling on the tube surface. Galling occurs when two metal surfaces in relative motion stick to each other through molecular forces, leading to frictional damage or seizing. The low coefficient of friction of AMPCO® alloys minimizes the risk of adhesion between sliding surfaces, reducing the chance of galling.

Regarding the tearing of tubes, AMPCO® is specifically designed for heavy-duty applications involving wear, abrasion, and fatigue. Its absence of nickel reduces the risk of mechanical abrasion with mating steel surfaces. AMPCO® alloys provide a good surface finish and sliding properties, preventing seizing or sticking on the bent tube and avoiding sudden stops that could cause tearing.

The role of wiper dies in eliminating humps: A hump in the bending process refers to a deformation that occurs when the material exceeds its elastic limit and sets in the curve of the bend die cavity at the end of the bend. The wiper die fills the gap between the bend die and the tube, opposite the pressure die. It stops material from bunching up behind the bend, ensuring a smooth bend without humps at the trailing end of the inside radius.

By covering the area where humps typically occur, the wiper die forces the tube to hold its shape, properly distributing pressure during the bending process.

Material science and copper-based alloys

In tube bending, selecting material is critical in determining the quality, durability, and performance of bent components. This chapter examines the material science behind copper-based alloys, with a particular focus on the properties and advantages offered by AMPCO® alloys.

Understanding material properties in tube bending

One of the most significant challenges in tube bending is springback, which is the tendency of the tube to return to its original shape after bending. The extent of springback is influenced by the material's hardness, with harder materials exhibiting more pronounced springback. Materials such as aluminum and copper alloys have lower springback tendencies compared to stainless steel and Inconel. Elongation is a crucial property for the precise bending of tubes without fracturing or tearing the material. Materials with high elongation characteristics can stretch and conform to tight bend radii without failure. The elongation percentage required for successful bending can be calculated using the following formula:

$$\%Elongation = \left(\frac{0.5 \times TubeOD}{CenterlineRadius}\right) \times 100$$

For instance, achieving a 1D bend (where the centerline radius equals the tube diameter) typically requires a minimum elongation of around 50 % in theory. However, practical bend quality can often be achieved with slightly lower elongation percentages (e.g., 35 - 40%) through meticulous tool design, machining, and precise bending tool setup.

Why AMPCO® alloys are key

The quality of tube bending relies on various factors, including the tube material, tool material, lubrication, and the bending machine itself. Among these, the selection of appropriate materials for tooling is crucial for achieving perfect bends without defects. Copper-based alloys such as aluminum bronze offer great advantages when it comes to tube bending tools. Mandrels and wiper dies in AMPCO® bronze provide a high-quality surface finish with an easy set-up, while maintaining minimum friction, no seizing, scratching, or corrosion starting point.

Understanding the properties and grades of tube materials is essential. Different materials, such as various grades of stainless steel (SS304, 409, 441, 316), Inconel, Titanium, and high tensile tubes, require specific types of bending tools. For these materials, nonferrous alloys like AMPCO® 21, AMPCO® 18.23, AMPCO® 18, and AMPCO® M4 are recommended. Using ferrous materials for these tube grades often results in galling, scratch marks on the bending surface, or scoring marks inside the tube. This is why AMPCO® alloys are favored for stainless steel, Inconel, Titanium, and high-tensile tube materials.

Final Thoughts

AMPCO® alloys offer excellent elongation and formability, allowing them to withstand bending without fracturing or tearing. Their superior sliding characteristics reduce friction during bending, promoting a smooth surface finish on bent tubes and minimizing the need for additional coatings or surface treatments. Moreover, their durability and resistance to wear ensure longevity in continuous use, making them ideal for consumables like wiper dies and mandrels. For copper and aluminum tubes, ferrous materials with special coatings are recommended for consumables to ensure optimal performance and tool life.

Future of tube bending

The future landscape of tube bending is poised for transformation with the integration of cutting-edge technologies that enhance precision, efficiency, and sustainability. This chapter presents an analysis of emerging trends and innovations that are shaping the trajectory of tube bending processes and technologies.

Automation and robotics integration

The integration of automation and robotics is set to transform tube bending operations. Advanced computer numerical control (CNC) machines equipped with robotic loading/unloading capabilities, automated tool changes, and real-time monitoring systems enable higher productivity, precision, and flexibility in production.

Artificial intelligence (AI) and machine learning algorithms are being deployed to optimize bending processes, predict tube behavior, and enhance programming efficiency. AI-powered simulations can predict causes and defects, fine-tune processes, and suggest ideal bend sequences to minimize scrap and ensure consistent quality.

1) Material analysis

AI algorithms analyze material properties such as ductility, hardness, and elasticity to determine optimal bending parameters. This ensures that the material does not crack or deform excessively during bending.

2) Geometry and tolerances

Artificial intelligence (AI) considers the geometry of the part, its thickness, and the specified tolerances to determine the most effective bending approach. It optimizes the bend direction, angle, and radius to minimize distortion and meet the design requirements.

3) Bend sequence optimization

Advanced algorithms, in conjunction with AI, are employed to evaluate different bend sequences to minimize scrap and production time. The bending process is simulated virtually, with potential issues identified and sequences adjusted accordingly.

Internet of Things (IoT) integration

The integration of IoT-enabled sensors into tube bending machines enables the collection of real-time data on parameters such as temperature, pressure, and force during the bending process. This data-driven approach facilitates the optimization of bending parameters, the detection of inconsistencies, and the assurance of uniform quality.

The deployment of IoT sensors in tube bending machines facilitates predictive maintenance by monitoring machine health indicators and wear patterns. Maintenance teams are thereby able to receive alerts about potential issues, preventing unexpected breakdowns and minimizing downtime.

The integration of IoT connectivity enables remote monitoring of tube bending machines, empowering operators to track production progress, troubleshoot issues, and make real-time adjustments from any location. This enhances operational flexibility and responsiveness.

Advanced materials and alloys

The demand for specialized alloys with superior mechanical properties is driving innovation in material science. Advanced materials such as titanium alloys, high-strength steels, and composite materials are being tailored for tube bending applications, offering enhanced performance and durability.

The development of smart materials and coatings with self-healing properties, wear resistance, and reduced friction is revolutionizing tooling and die designs. These innovations contribute to longer tool life, improved surface finish, and reduced maintenance requirements.

Final Thoughts

The future of tube bending is marked by a convergence of automation, AI-driven optimization, IoT-enabled smart manufacturing, and advanced material science. By embracing these technologies, manufacturers can achieve higher levels of precision, efficiency, and sustainability in tube bending processes. In the subsequent chapter, we will explore practical design tips and safety best practices to leverage these advancements and optimize tube bending operations for diverse applications and industries.

Tube bending design tips and safety best practices

This chapter offers essential design tips for engineers and outlines safety best practices in tube bending operations. It emphasizes the importance of optimizing tube components for efficient production and ensuring operator safety.

Tube bending design tips for engineers

1) Understanding machine capabilities

Designers should have a comprehensive understanding of the capabilities and limitations of tube bending machines. This knowledge ensures that specified tube components are optimized for production without compromising functionality. Considerations include the tube material, configuration, and required tooling, such as wiper dies and mandrels.

2) Material selection for tooling

Select durable materials for tooling components such as benders, clamps, and dies with high elongation limits to facilitate fabrication or machining. Select consumable materials such as wiper dies and mandrels based on compatibility with the tube material to avoid galling, scratching, or scoring.

3) Tube component drawing analysis

A critical analysis of tube component drawings should be conducted to determine the necessity for single-stack or multi-stack tooling based on the centerline radius (CLR) and the optimal configuration of the tooling to achieve the desired bend profiles. The bend shapes and bend angles should also be evaluated.

4) Minimize waste

It is of great importance to plan bend sequences strategically to minimize the amount of scrap material produced. Furthermore, it is essential to optimize tube lengths and bending sequences to reduce material waste and improve overall production efficiency.

5) Understanding tube bending machines

It is important to familiarize oneself with the specific tube bending machine's maximum capacity, capability, and features. It is also essential to ensure proper tool mounting and fitment to align with machine specifications and functionalities.

Safety best practices in tube bending operations

1) Safety mats

The implementation of safety mats around the tube bending machine serves to enhance operator safety. When an operator steps on the mat, it triggers the machine to cease operation, thereby preventing accidents or injuries.

2) Optical sensors or laser scanners

The use of optical sensors or laser scanners below the tube bending machine is recommended to create an invisible safety boundary. These devices are capable of detecting the presence of operators and can halt machine operations if the safety zone is breached.

3) General safety guidelines

- It is inadvisable to rely solely on safety devices; it is important to maintain awareness and caution at all times.
- Hands should be kept clear of clamping areas during machine operation to prevent injuries.
- It is recommended that one operator be assigned to each machine to minimize confusion and maintain focus on safe operation.
- It is strongly advised that no one stand between an open bend arm and the body of the machine during operation.
- It is essential to follow the safety instructions provided on the machine and adhere to the recommended operational practices.
- It is crucial to ensure the proper positioning of carriage trolleys, clamp dies, and pressure dies to avoid tool damage and ensure smooth operation.

Final Thoughts

Implementing effective tube bending design practices and adhering to safety guidelines are essential for optimizing production efficiency and ensuring a safe working environment. By integrating these design tips and safety best practices into tube bending operations, engineers and operators can achieve high-quality bends while prioritizing workplace safety.