TECHNICAL BULLETIN

PROGRESSING CAVITY PUMPS | LS-TB-O26

LIFTING SOLUTIONS

BULLETIN NO.	TOPIC	ISSUE DATE	ISSUED BY
LS-TB-026 V1	PCP ROTOR CHROME THICKNESS	NOV 17, 2021	ENGINEERING

BACKGROUND

Progressing cavity (PC) pump rotors are normally manufactured from a moderate to high strength carbon or alloy steel material with stainless steel materials being used occasionally for severely corrosive application conditions. Lifting Solutions uses as its standard rotor bar material 4140/4142 low alloy steel with chromium and molybdenum that is heat treated and stress relieved. This material has a minimum yield strength varying from 95 to 110 ksi and minimum tensile strength varying from 115 to 130 ksi depending on bar diameter with larger bars having the lower values. The associated hardness range of this material is 28 to 36 HRC.

To ensure maximum durability PC pump rotors are normally chrome plated through an electroplating process which results in a surface hardness of 66 to 70 HRC (850 to 1150 HV). The chrome coating is relatively impermeable to fluids and gas thus providing protection of the rotor bar material from corrosive damage. Lifting Solutions coordinates the rotor chroming through two third party suppliers that specialize in coating PC pump rotors, each of which have over 25 years' experience. These suppliers utilize the HEEF® 25 chrome solution which is a high speed etch free process that generates higher hardness and an increased level of micro-cracks thus representing an improvement over legacy ordinary chrome solutions. The HEEF® process provides many advantages including corrosion resistance, wear resistance and reduced coefficient of friction. The chrome coating is applied to Lifting Solutions specifications and a variety of quality control checks are done to ensure conformance.

ROTOR CHROME COATING PROCESS OVERVIEW

Rotors after machining to size have machining marks that vary in severity depending on the rotor geometry with shorter pitches and higher eccentricity being more aggressive. When required, these marks are removed via a light polishing that typically removes less than 0.001" (25 µm) of material but with aggressive models can approach 0.002" (50 µm). Subsequently the rotors have their surface cleaned and activated before being placed in a heated chromium bath. The chrome electroplating process involves electricity being applied to the bath system creating a potential difference between the rotor which acts as a cathode and anodes that surround the outside of the rotor. This results in chromium metal ions transferring from the solution and depositing on the rotor surface. The deposition rate is a function of many parameters, but the upper range is typically about 0.001" (25 µm) per hour resulting in a relatively long process for the thick chrome coatings applied to PC pumps rotors.

One of the important parameters that determines the chrome deposition rate is the distance between the anode and the cathode with closer distances resulting in higher deposition rates. Because the PC pump rotor has a varying diameter the deposition rates are higher on the rotor high spots (peaks) that are closer to the anode than the rotor low spots (valleys) that are further away as illustrated in Figure 1. The rotor pitch also impacts the uniformity of the peak and valley deposition with longer pitch rotors having more similar deposition rates between the peaks and valleys. For rotors, the variation in deposition rate is designated as the *rotor chrome ratio* and defined as the ratio of the thickness on the peak to the valley. This ratio varies from slightly over one, to as high as four, depending on the rotor geometry. Additionally, as the chrome thickness builds on the rotor the deposition rate decreases resulting in the nature of the chrome deposition changing along with the associated chrome deposition ratio.

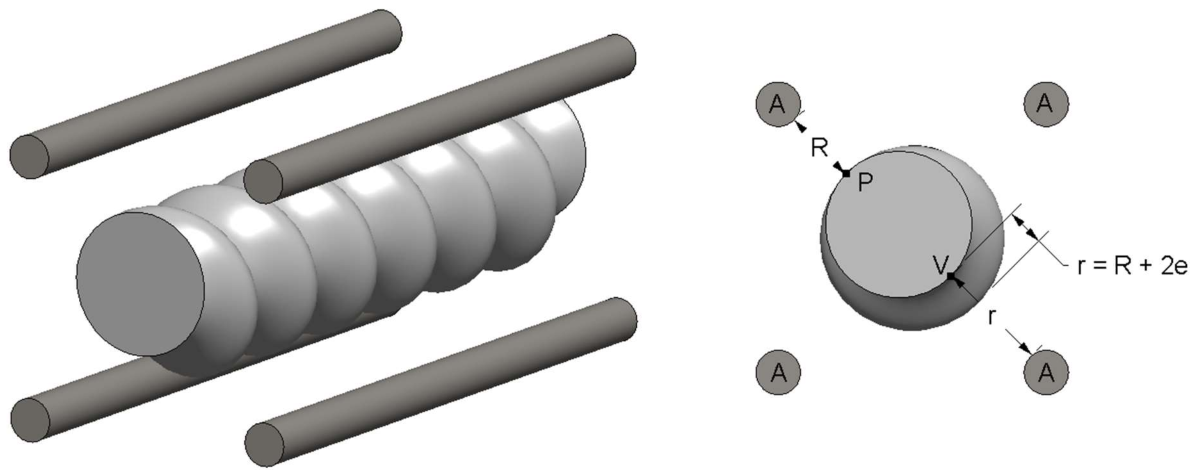


Figure 1: Rotor placement in chrome tank showing peaks (P) are closer to the anodes (A) than the valleys (V)

Figure 2 illustrates the chrome depositions relative to the underlying rotor base material and the associated differences in chrome thicknesses around the profile for T2 and T4 rotor coating thickness codes.

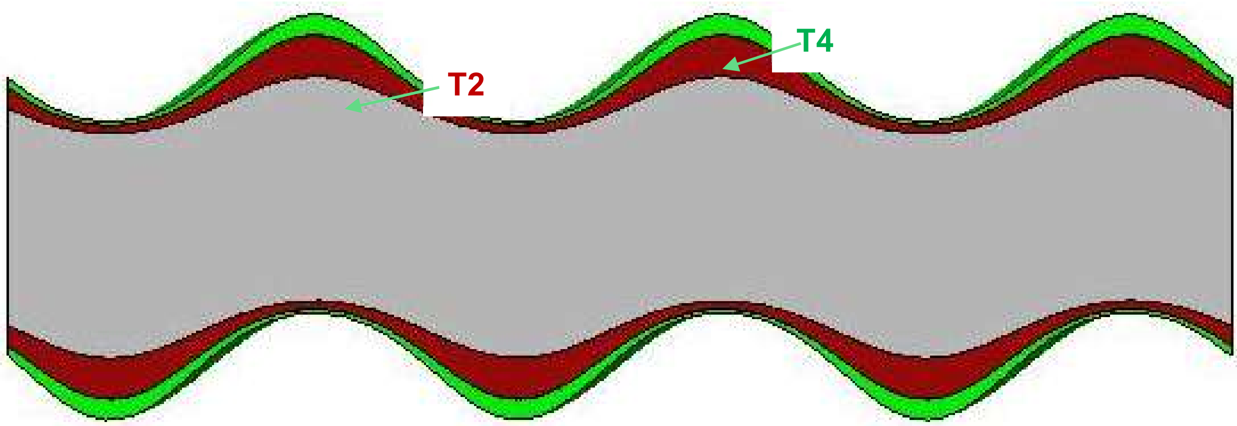


Figure 2: Rotor placement in chrome tank showing peaks (P) are closer to the anodes (A) than the valleys (V)

When high chrome thicknesses are combined with rotor geometries with high chrome ratios it is difficult to reliably control the shape of the rotor profile leading to the potential for distorted profiles. Additional figures included in the Appendix section are obtained via 3D laser scanning of two rotor geometries, each with T2 and T4 coating thickness codes, and the scan results are compared to the theoretical rotor shapes with circular cross-section using computer software illustrating the final rotor shapes.

ROTOR DESIGN AND MANUFACTURING

PC pump rotor size and shape dictate the interference fit with the stator which in turn plays a significant role in pump performance and longevity. As a result, PC pump manufacturers must coordinate closely with third party chrome suppliers to ensure the desired final rotor size. PC pump manufacturers define for a specific model and application the target finished rotor size to achieve the desired pump test performance and associated downhole performance. Rotor machining sizes are then determined based on the chrome thickness requirements and the nature of the chroming process for each specific case. This is done so that after the rotor is machined, and where necessary polished resulting in material removal, the natural chrome deposition results in the targeted final rotor size and associated shape. While it is possible to adjust the rotor size post chroming, it is difficult to remove material due to the high hardness associated with the chrome. Additionally, the manual nature of most rotor polishing operations gives rise to the potential for rotor profile distortion and/or lack of uniformity along the length negatively impacting the finished product dimensional tolerance.

Typical chrome electroplating applications have thicknesses of 0.003 to 0.005” (75 to 125 µm) but because of the requirement for PC pumps to operate for extended periods (years) and associated operating cycles (100 to 600 million), in some cases with poorly lubricated or abrasive fluids, higher thicknesses are used. Because the rotor peak is the primary contact/wear area, the chrome thickness in this area is the standard PC pump industry reference. PC pump peak chrome thicknesses across the downhole PC pump industry are typically 0.010 to 0.015” (250 to 375 µm) but rise to 0.015 to 0.020” (375 to 500 µm) for applications with severe abrasives.

Lifting Solutions defines T1, T2 and T3 standard *chrome thickness levels* based on minimum peak thicknesses of 0.012, 0.015 and 0.020” (300, 375 and 500 µm) respectively. Although not common, a T4 thickness of 0.0225” (575 µm) is available which is the maximum thickness based on practical chrome coating limitations. Values above this are also not recommended from the product application standpoint due to the potential for severe chrome cracking that allows produced fluids to access the underlying rotor base material; chrome delamination that results in loss of sections of chrome compromising the rotor/stator fit and damaging the stator elastomer; and thick coatings resulting in a brittle surface layer that is prone to damage from severe contact/impact and bending. Caution should be used in deploying high chrome thickness levels in combination with geometries that have high chrome ratios to avoid inconsistencies in the rotor profile shape or distorted rotor profiles that can have a detrimental impact on pump performance and longevity.

The PC pump rotor major diameter is comprised of two peaks and the rotor minor diameter is comprised of a peak and a valley as shown in Figure 3. The nature of rotor/stator interaction is that the most aggressive seal-line contact occurs on the rotor peaks which fortunately is where the chrome deposits in the thickest layer. As described above, Lifting Solutions has several standard chrome thickness levels that are selected based on the application requirement. As part of the chrome thickness level selection process consideration is also given to chrome thickness on the valley which is determined by the pump geometry and associated chrome ratio. While the chrome in the valley is less prone to wear, sufficient chrome thickness is still required as a barrier to prevent fluid and gas attack of the rotor base material. To ensure protection of these valley surfaces, Lifting Solutions, based on extensive operational experience across a wide range of applications, has a minimum valley chrome thickness specification of 0.004” (100 µm). For most pump geometries this minimum, and typically much higher values, are achieved even with the lowest T1 thickness of 0.012” (300 µm). However, for pump geometries with high chrome ratios this minimum valley requirement necessitates going up to a higher chrome thickness level. As an example, a model with a chrome ratio of four with a T1 peak thickness of 0.012” (300 µm) would only have 0.003” (75 µm) on the valley and as such would need to have a minimum T2 peak thickness of 0.015” (375 µm) to produce 0.004” (100 µm) on the valley.

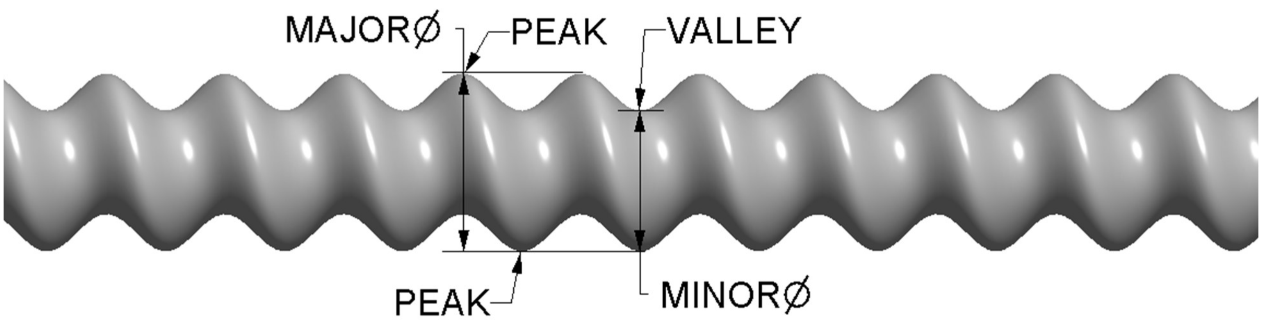


Figure 3: Rotor Major Ø and Minor Ø in reference to Rotor Peaks and Valleys

PUMP GEOMETRIES AND CHROME THICKNESS

Lifting Solutions pump geometries and their corresponding chrome ratios and associated peak and valley chrome thicknesses for the various chrome thickness levels are summarized in Table 1. Rotor profiles are shown graphically and illustrate that the shorter pitch pumps have higher chrome ratios eliminating the option of the T1 and in some cases T2 to ensure compliance to the Lifting Solutions minimum valley coating thickness specification.

CHROME THICKNESS QUALITY CONTROL

Lifting Solutions measures the as-machined rotor major and minor diameters at multiple locations along the rotor length. Subsequently, the chrome suppliers as well as Lifting Solutions measure the final chromed rotor major and minor diameters. These measurements combined with the polishing allowance for the specific geometry allows the calculation of the inferred chrome thickness on the peaks and valleys to validate adherence to the required chrome thickness specification. An example of this measurement and calculation process including the chrome thickness ratio is included below. Additionally, select rotors are directly measured with a chrome thickness gauge at various locations along their length on the peaks and valleys. These measured values are compared to the inferred thickness values for confirmation.

Machined Major Ø: 2.000"; Machined Minor Ø: 1.500"

Polished Major Ø: 2.000" – 0.001" x 2 = 1.998"

Polished Minor Ø: 1.500" – 0.001" x 2 = 1.498"

Finished Major Ø: 2.228"; Finished Minor Ø: 1.523"

Peak Chrome Thickness = Finished Major Ø – Polished Major Ø /2

2.228" – 1.998" = 0.030"/2 = 0.015"

Valley Chrome Thickness = Finished Minor Ø – Polished Minor Ø – Peak Chrome Thickness

1.523 – 1.498 – 0.015" = 0.010"

Chrome Thickness Ratio = Peak Chrome Thickness/Valley Chrome Thickness

0.015/0.010 = 1.5

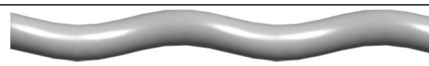
Model	Rotor Eccentricity (in.)	Rotor Swept Angle (°)	Default Coating Thickness Code (in.)	Default Peak Coating Thickness (in.)	Default Peak Coating Thickness (um)	Default Valley Coating Thickness (in.)	Default Valley Coating Thickness (um)	Rotor Profile Visualization
LS 7	0.169	32.1	T3	0.020	508	0.006	152	
CD 13	0.226	33.0	T2	0.015	381	0.006	152	
LS 15	0.234	34.2	T2	0.015	381	0.006	152	
LS 20	0.234	42.6	T2	0.015	381	0.008	203	
LS 31	0.349	35.4	T3	0.020	508	0.008	203	
LS 41	0.234	61.4	T2	0.015	381	0.011	279	
LS 43	0.254	55.5	T2	0.015	381	0.009	229	
LS 54	0.278	58.1	T2	0.015	381	0.009	229	
LS 61	0.329	54.5	T2	0.015	381	0.009	229	
LS 72	0.329	59.1	T2	0.015	381	0.011	279	
LS 87	0.329	63.5	T2	0.015	381	0.011	279	
LS 105	0.317	68.0	T2	0.015	381	0.012	305	
LS 118	0.445	52.0	T2	0.015	381	0.009	229	
LS 123	0.302	71.0	T2	0.015	381	0.012	305	

Table 1: Rotor coating thickness codes and associated peak and valley coating thicknesses for several PCP geometries.

APPENDIX

The differences between the actual rotor shape and the baseline rotor with circular cross-section are indicated by the color-coded lines and associated scale chart. The lines protruding outwards indicate the actual rotor profile is larger than the design/baseline profile. The blue and red profile lines are for reference only and represent offsets of +/- 0.010” (250 μm) when comparing the coated rotor profile against the underlying base material in Figures 4 and 5 and +/- 0.005” (125 μm) when comparing the coated rotor profile against the theoretical design profile of the target finished/coated size in Figures 6 and 7.

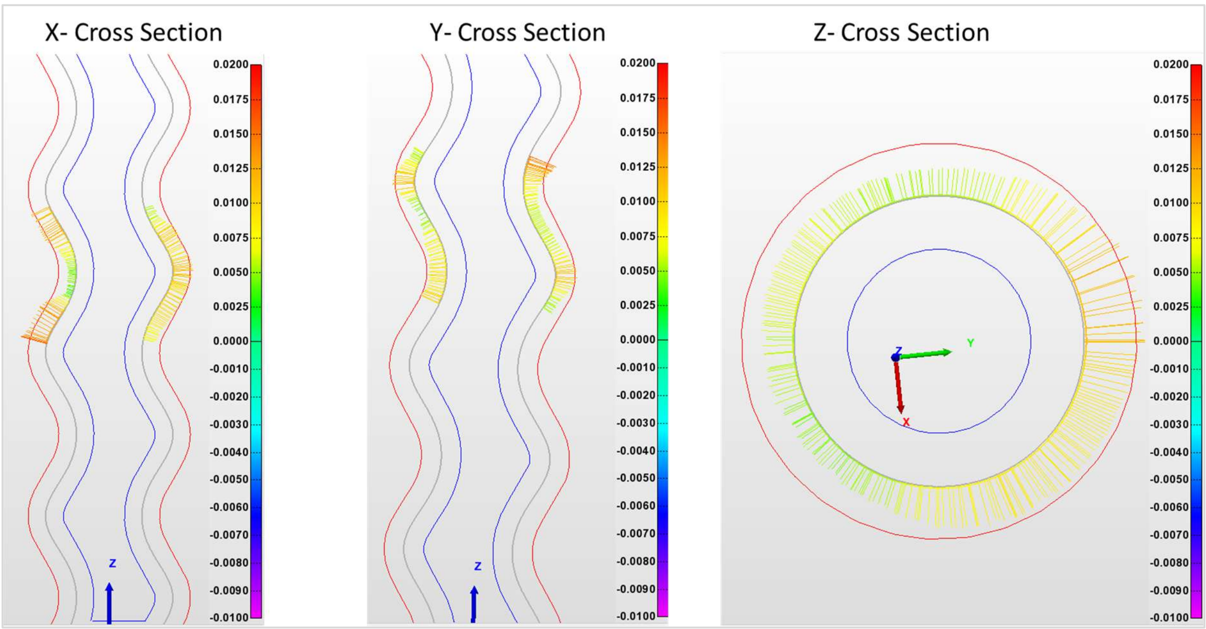


Figure 4a: Model CD 13 coating profile relative to underlying base material with T2 thickness code

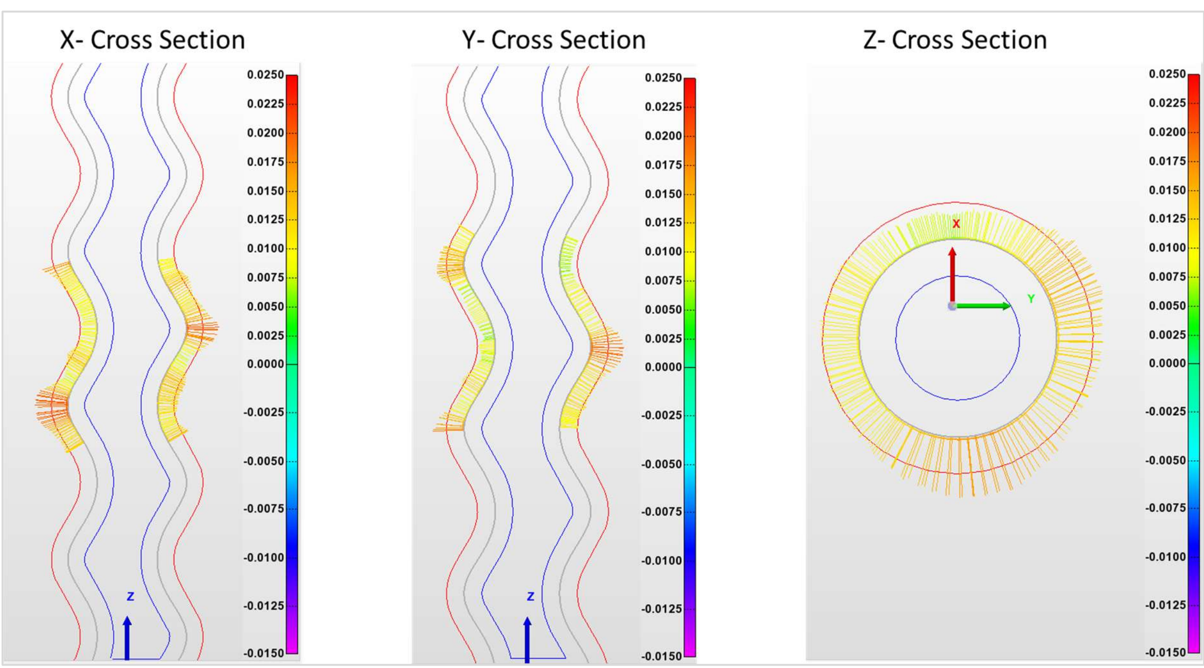


Figure 4b: Model CD 13 coating profile relative to underlying base material with T4 thickness code

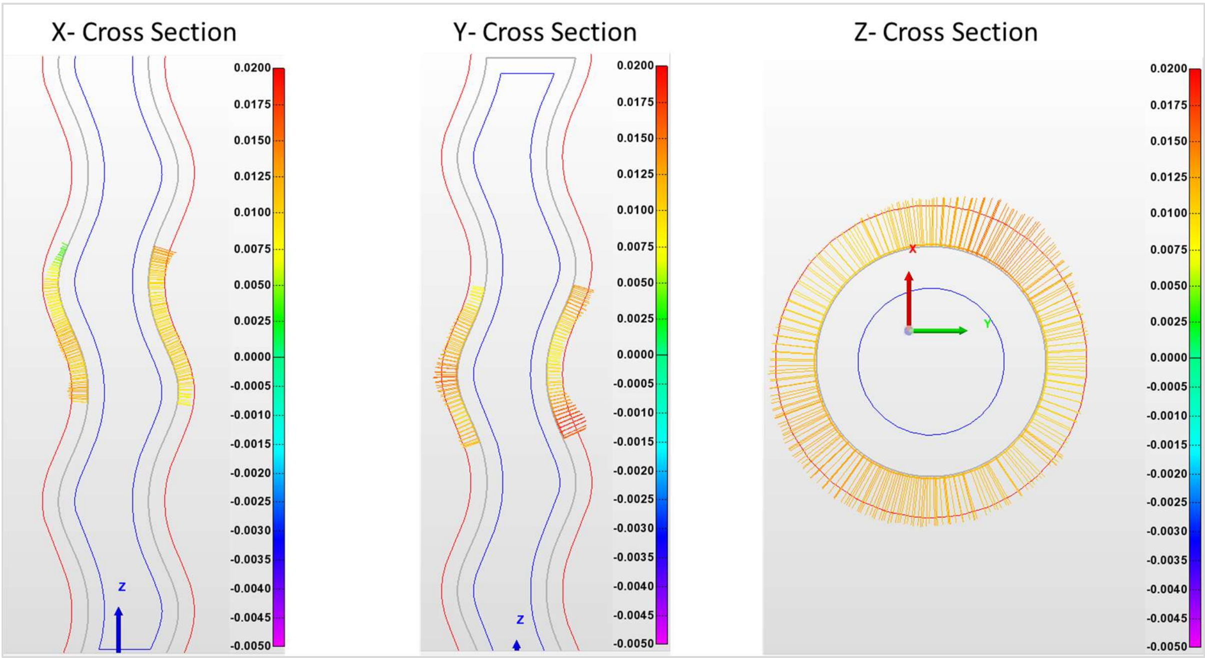


Figure 5a: Model 20 coating profile relative to underlying base material with T2 thickness code

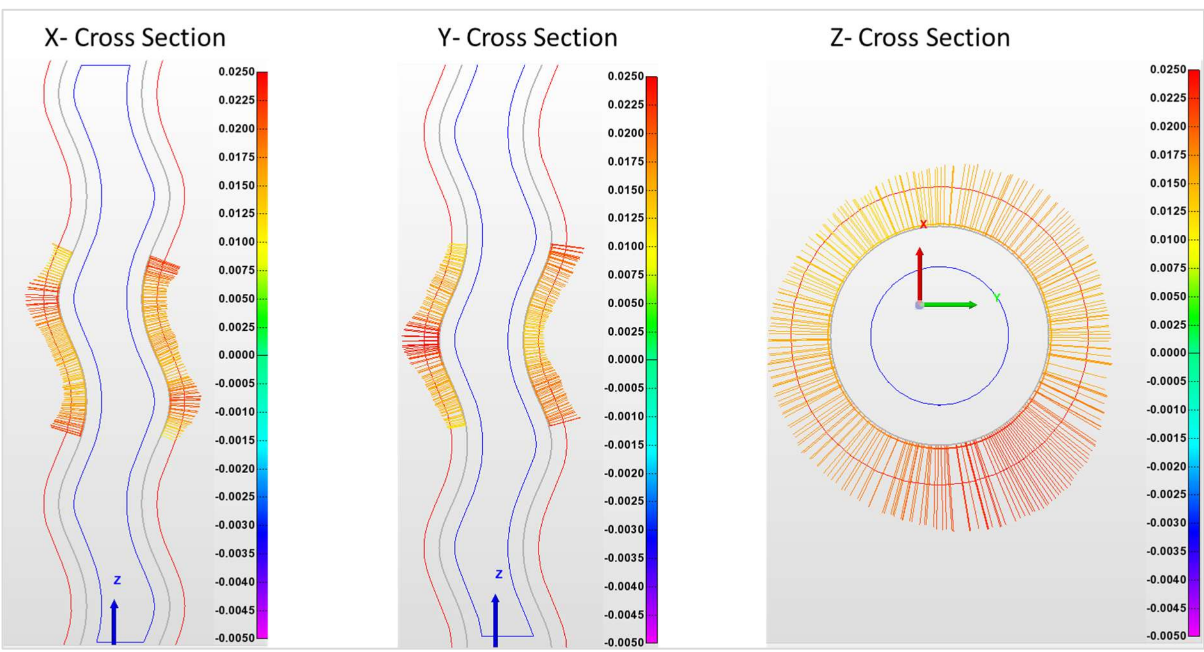


Figure 5b: Model 20 coating profile relative to underlying base material with T4 thickness code

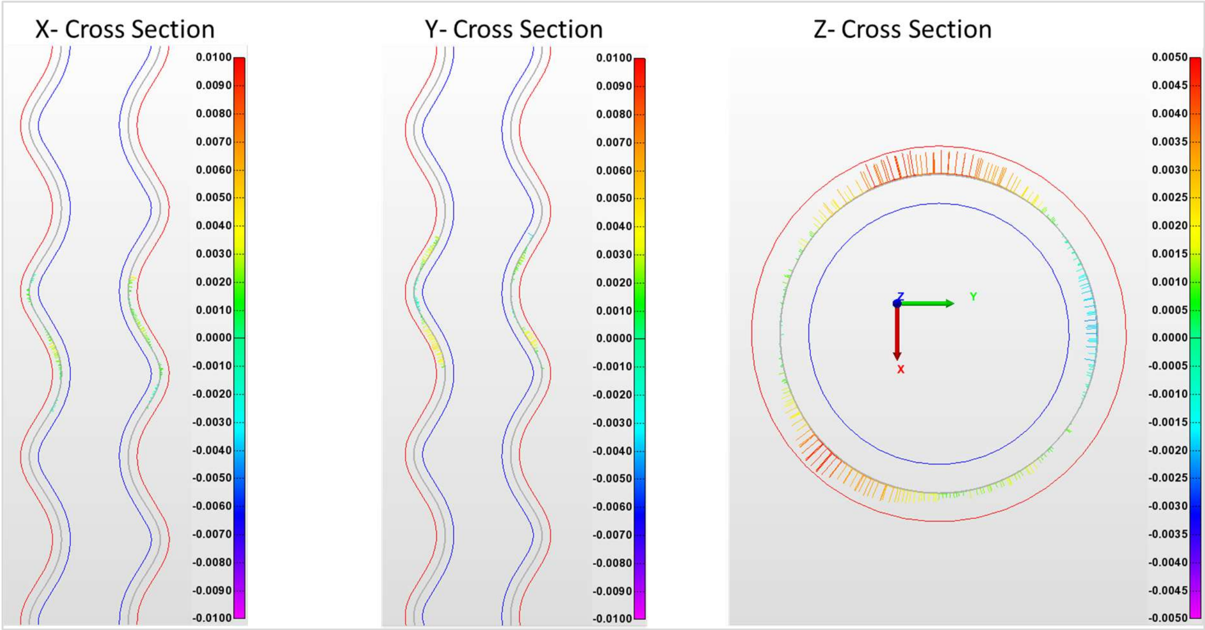


Figure 6a: Model CD 13 coating profile relative to theoretical design profile with T2 thickness code

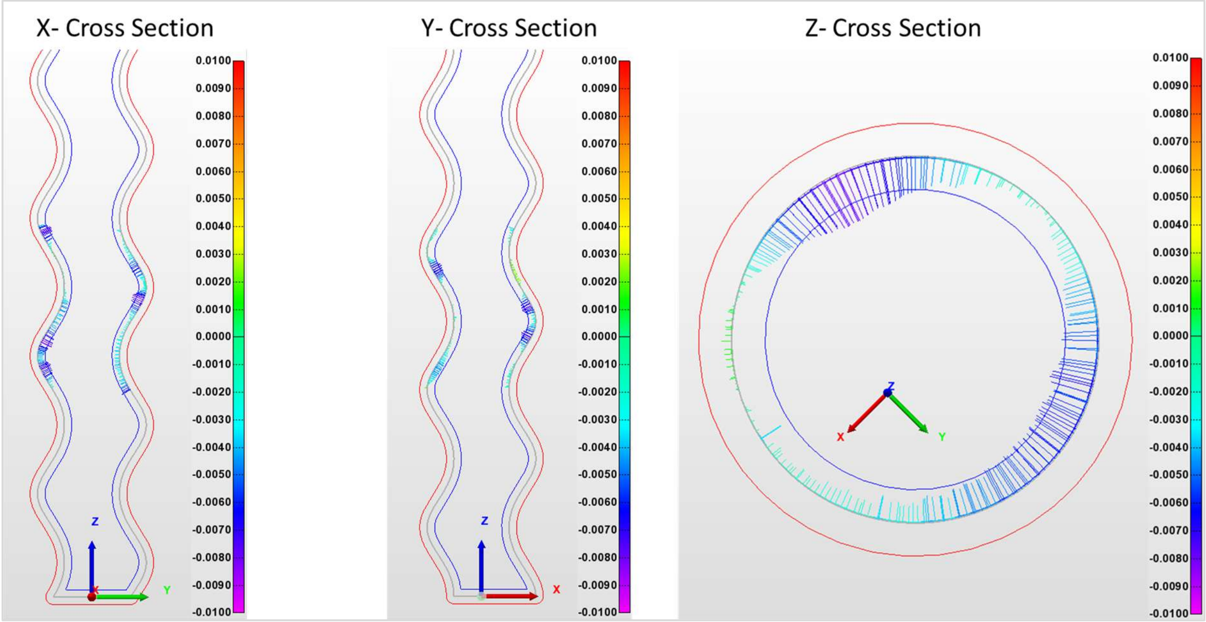


Figure 6b: Model CD 13 coating profile relative to theoretical design profile with T4 thickness code

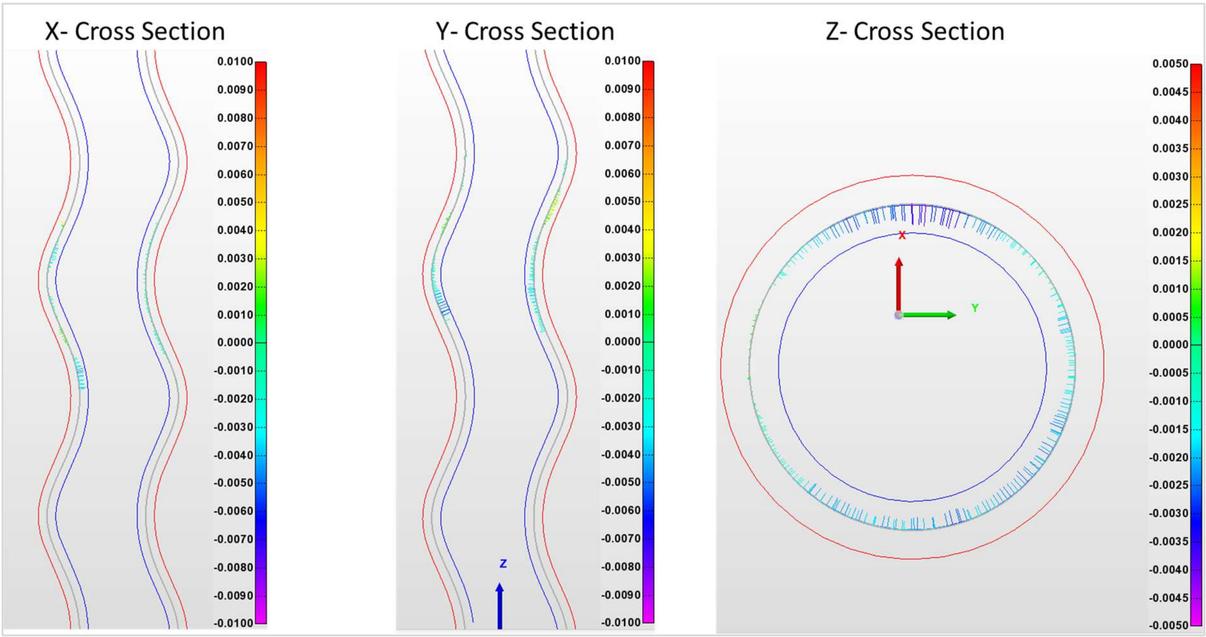


Figure 7a: Model 20 coating profile relative to theoretical design profile with T2 thickness code

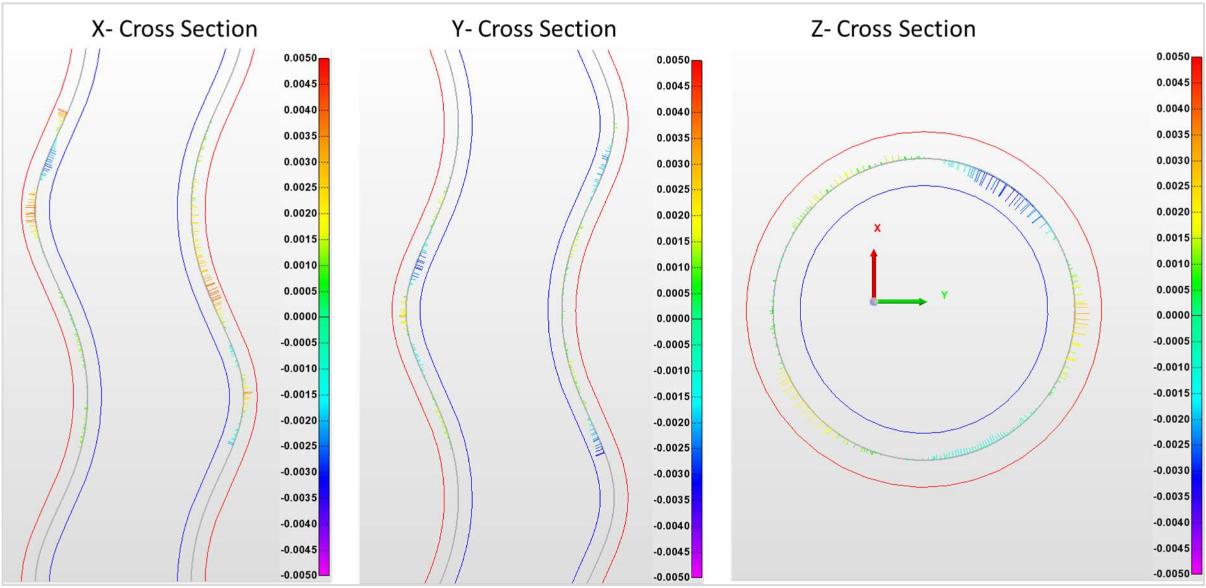


Figure 7b: Model 20 coating profile relative to theoretical design profile with T4 thickness code

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