Trimming Simulation of Forming Metal Sheets Isogeometric Models by Using NURBS Surfaces

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01.- MOTIVATION

02.- GENERAL VIEW

03.- TRIMMING CURVE DEFINITION

04.- STIFFNESS MATRIX AND FORCES

05.- EXAMPLES

06.- POTENTIAL IMPROVEMENTS

01.- MOTIVATION

At the end of forming it is usual to **trim the formed part** to achieve final shape or to remove edge micro-cracks

Due to plastic deformation during forming **residual stresses** are generated

After trimming there is a **redistribution** of the residual stresses and **displacements** to achieve a new equilibrium

It is necessary to define accurately the trimming line to be able to assess the new state

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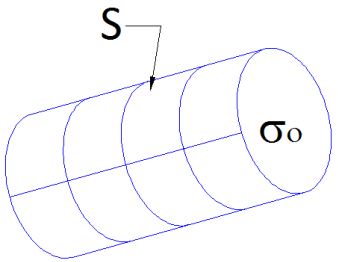
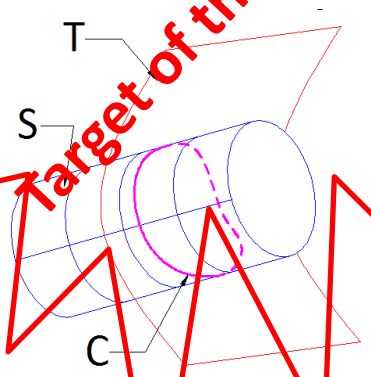
02.- GENERAL VIEW

0) At the end of forming there are defined:
-Part **geometry**
-**Material properties**
-**Residual stresses** $\{\sigma_o\}$
Stored in **surface model "S"**

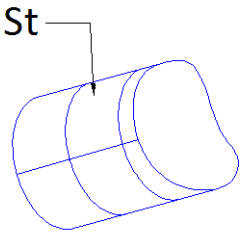


1) Surfaces **S**-**T** intersection is computed, the output is a trimming curve "**C**"



Target of this job

2) A portion of **S** is **removed and then deactivated** for subsequent calculations as [1]. The remaining surface is called "**St**"



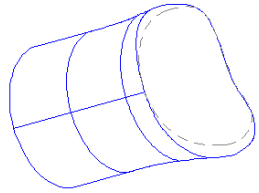
(Definition of trimming surface "**T**" - NURBS surface)

3) Control points forces due to residual stresses and stiffness matrix are calculated using the remaining area of **S** (St) in the integrals

$$\{f_{ecp}\} = -\int_V [B]^T \{\sigma_o\}\, dV$$

$$\{K_e\} = \int_V [B]^T\, [D][B] dV$$

4) Final configuration



[1] Kim HJ, Seo YD, Youn SK. *Isogeometric analysis for trimmed CAD surfaces*. Comput. Methods Appl. Mech. Engrg. 198 (2009) 2982–2995

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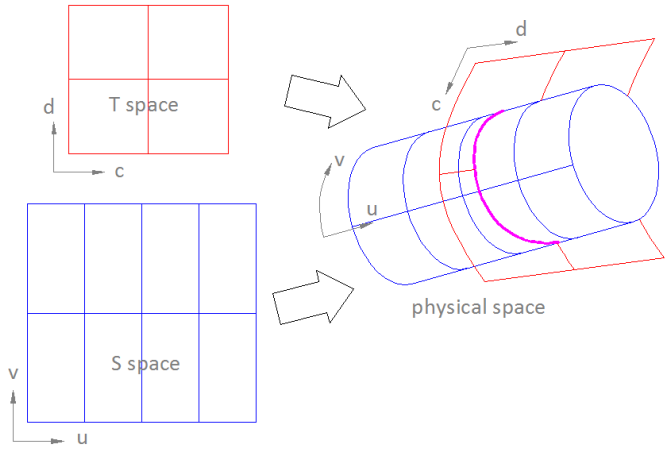
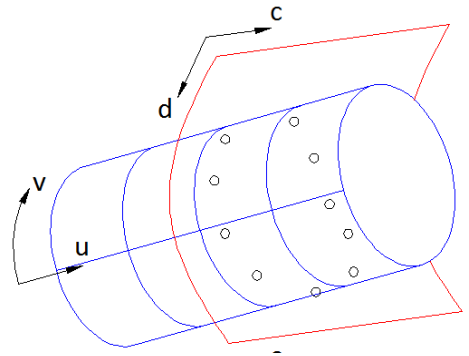
03.- TRIMMING CURVE DEFINITION

Surfaces S and T intersect in physical space but are defined in different parameter spaces → Iterations are required

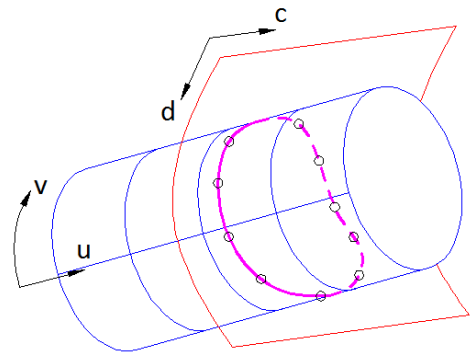
03.1.- Strategy
03.2.- T surface requirements
03.3.- Row of intersection points
03.4.- Curve fitting
03.5.- Definition of remaining surface



I .- Calculate a row of S-T intersection points (iterations required for each intersection point calculation)



II .- Fit a curve to the row of intersection points but in **S parameter space**



03.- TRIMMING CURVE DEFINITION

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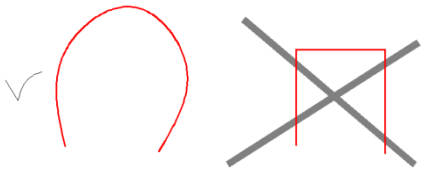
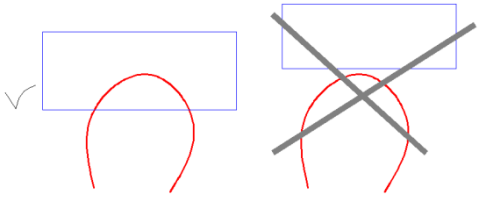
Trimming T surface has to:

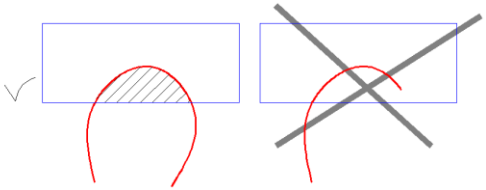
Be smooth (derivable)



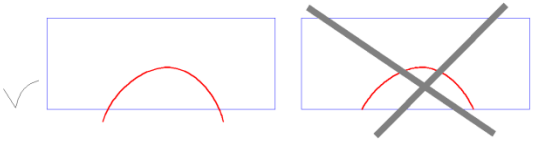
Trim the metal sheet in the physical space



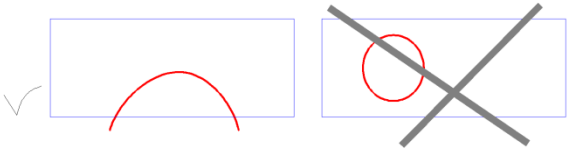
The resulting trimming curve has to enclose a portion of S surface



Extend slightly further than the intersection between the two surfaces



Be open surface



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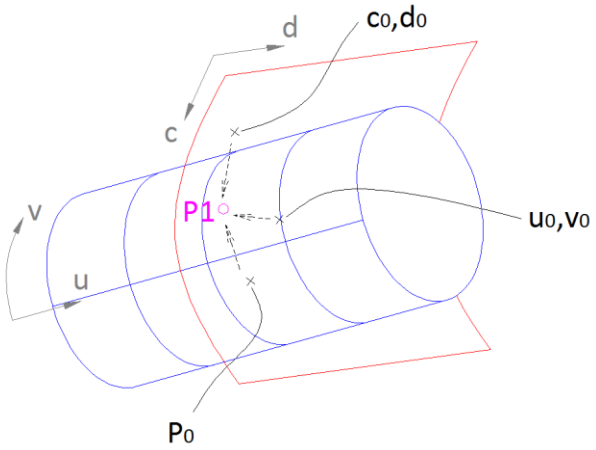

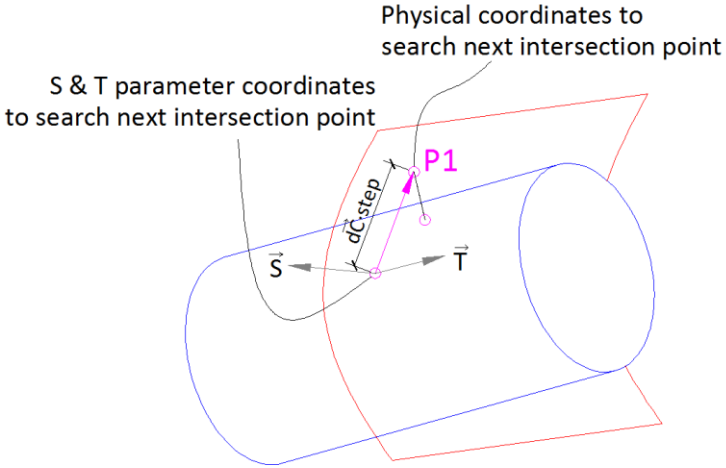

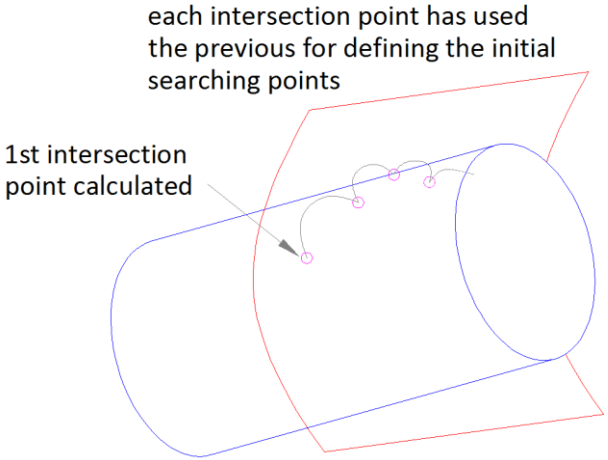

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Function [X,s,t]= **RowInterPoints** (P0 , u0,v0, c0,d0 , S,T , step)

Initial searching point

Surfaces parameters

Step to calculate next searching point

```
P1 = P0            % transfers
Suv1 = (u0,v0)   % initial searching
Tcd1 = (c0,d0)   % points

i=1
While Dx > tolerance
    P2,Suv2,Tcd2 = intersection (P1,Suv1,Tcd1)    % computes the closest intersection point to searching point P1.

    X(i) = P2 ;  s(i) = Suv2;   t(i) = Tcd2          % transfers intersection point to answer arrays

    Suv1 = Suv2 ; Tcd1 = Tcd2                          % updates initial searching points in S and T parameter  spaces

    dC = derivative(P2,Suv2,Tcd2)                    % calculates next physical coordinates of searching point using
    P1 = P2 + dC*step                                  % the derivative at the latest intersection point and the step

    Dx = abs( |X(i) | - |X(i-1) | )      % calculates the distance between the two latest intersection points
                                                        % if is zero means that the edge of S surface is reached and the loop halts
    i = i+1
End while

End function
```

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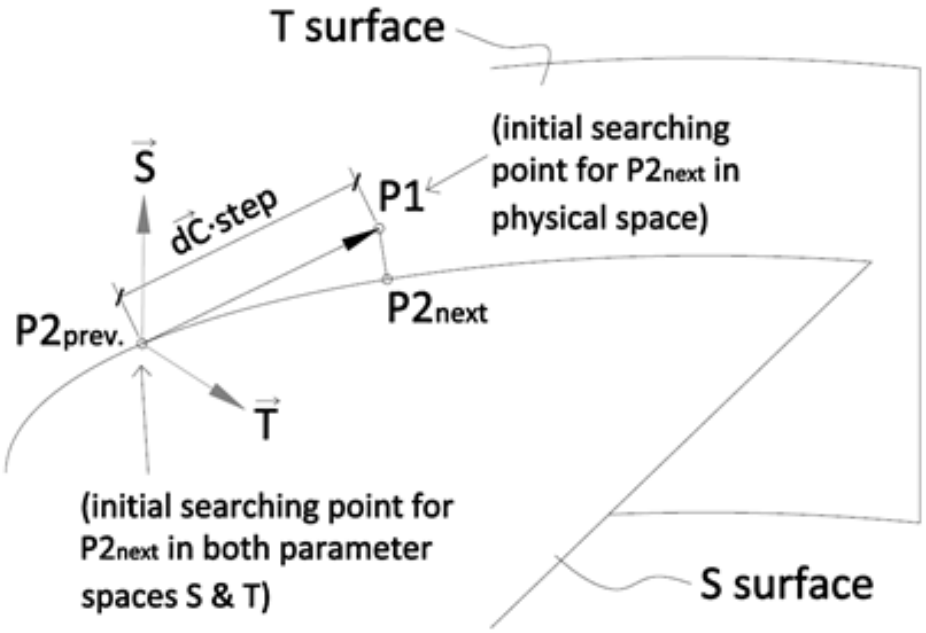

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Row of intersection points in parameter space S

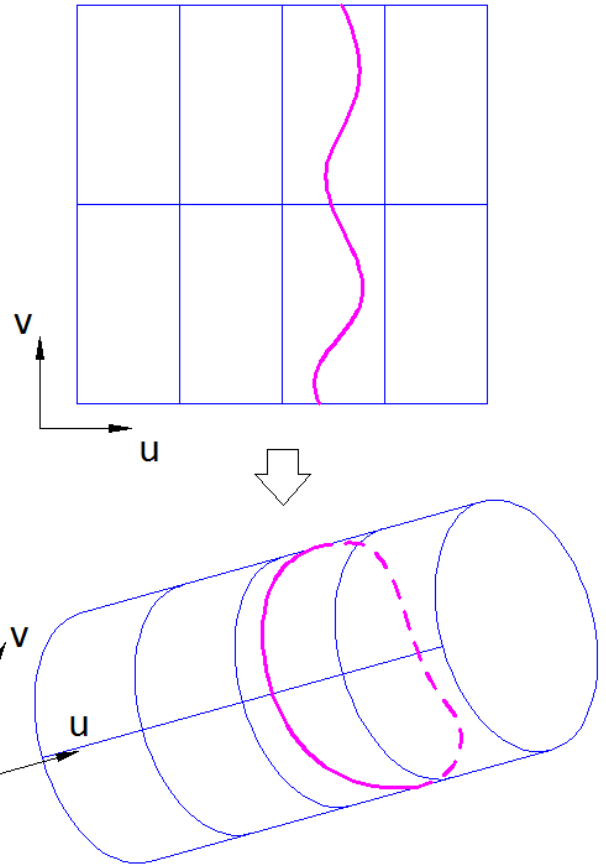
"global curve interpolation to point data" [2]

Fit a B-spline in parameter space S

Curve parameter space C

Parameter space S

Physical space



[2] Piegl L, Tiller W. *The NURBS Book. Berlin*. Springer-Verlag, (1996).

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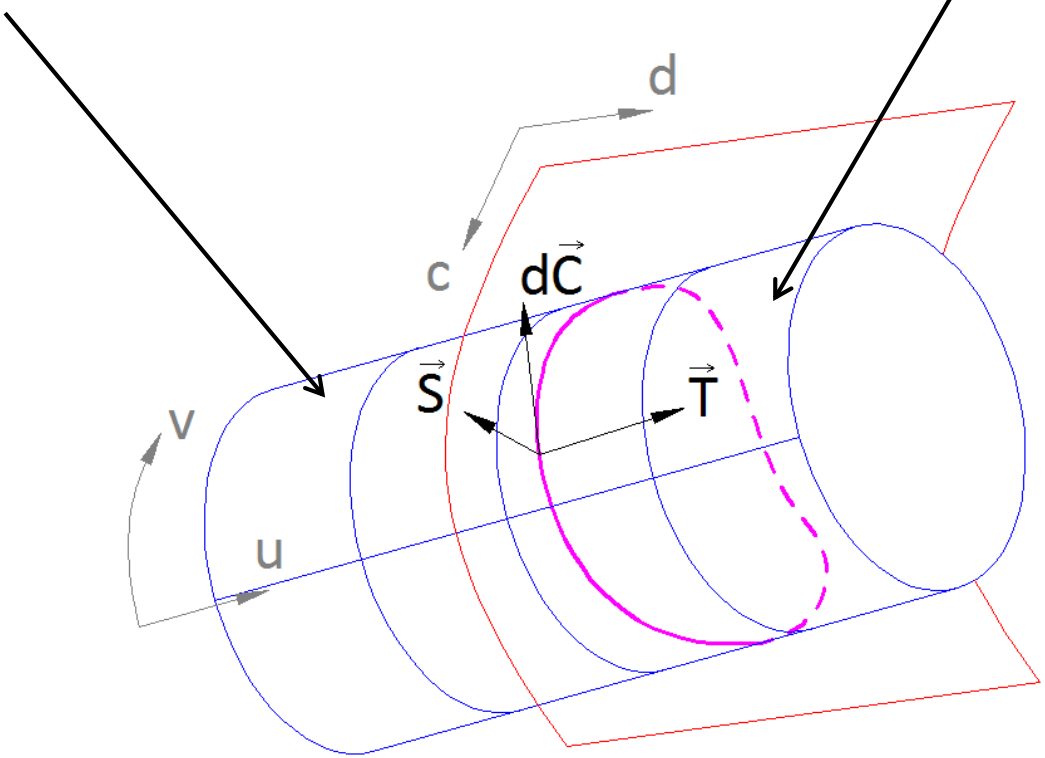
Direction of curve is given by cross product of surfaces S and T normal vectors

$$d\vec{c} = \vec{S} \times \vec{T}$$

Surface on the left hand side of the trimming curve remains

Surface on the right hand side is to be removed



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04.- STIFFNESS MATRIX AND FORCES

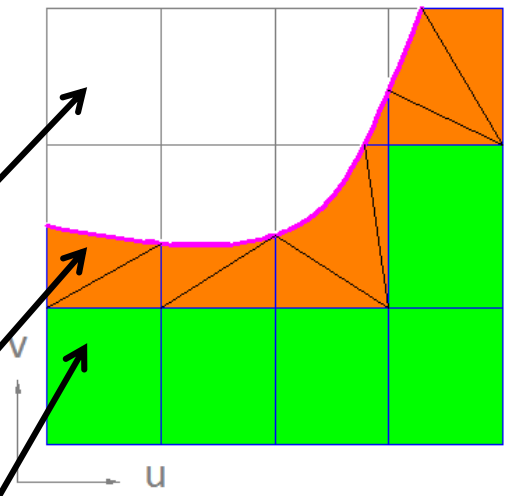
Already developed for trimmed 2D surfaces by Kim *et al.* [1]. Here we proceed in a similar manner

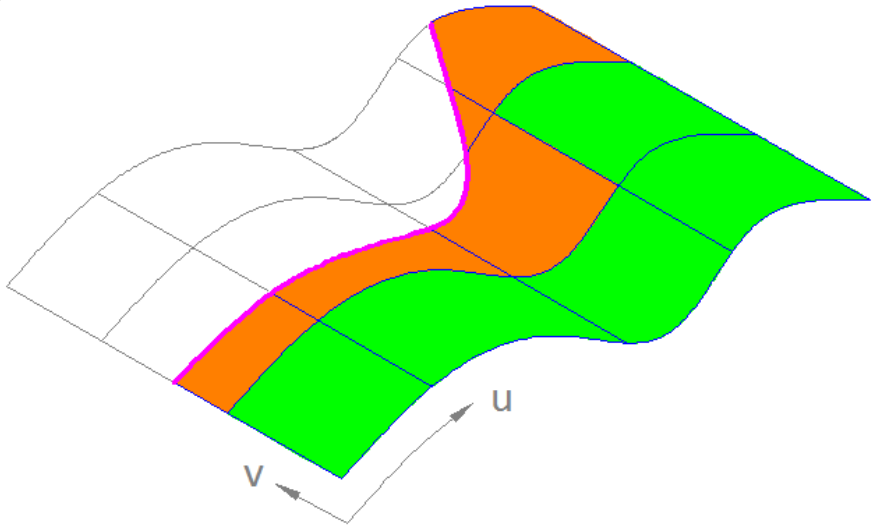
When computing [Ke] and {fecp} at each element:

- **Ignore** totally deactivated elements

- For trimmed elements: **divide** into triangles remaining area and integrate those triangles

- Integrate in a **standard** manner totally in elements





Then the control points displacement are calculated and afterwards the stresses

[1] Kim HJ, Seo YD, Youn SK. *Isogeometric analysis for trimmed CAD surfaces*. Comput. Methods Appl. Mech. Engrg. 198 (2009) 2982–2995

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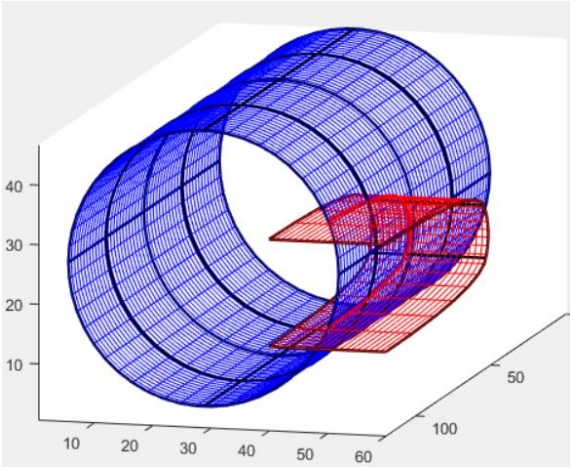
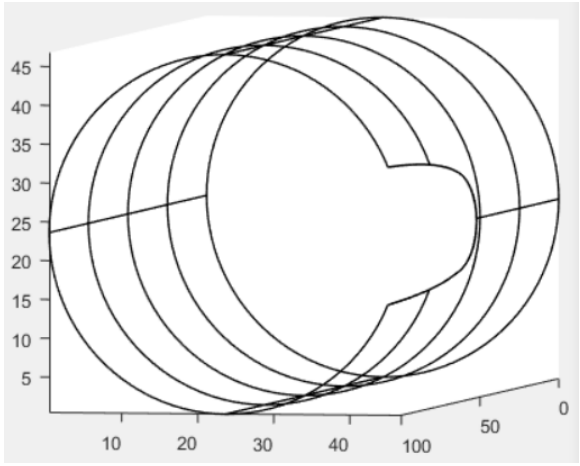
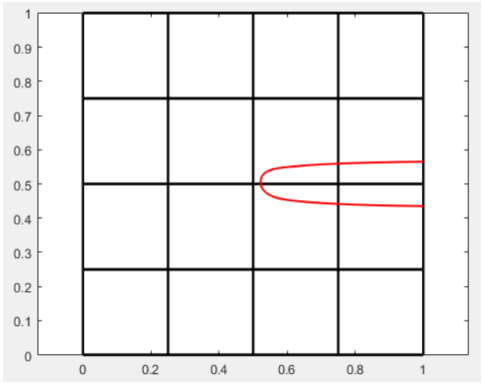
04.- EXAMPLES

Trimming examples:

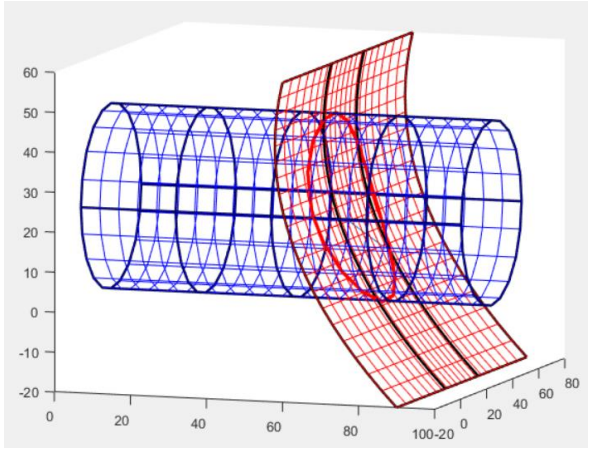
- slotted pipe:

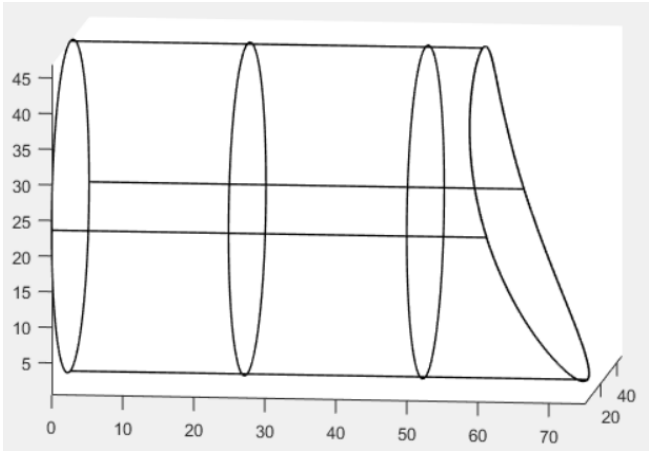


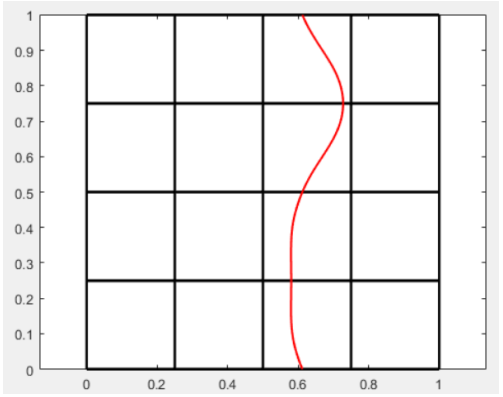




- end-trimmed pipe:



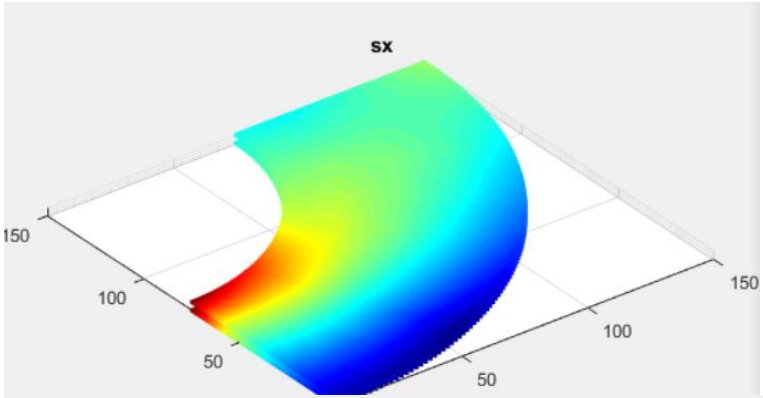


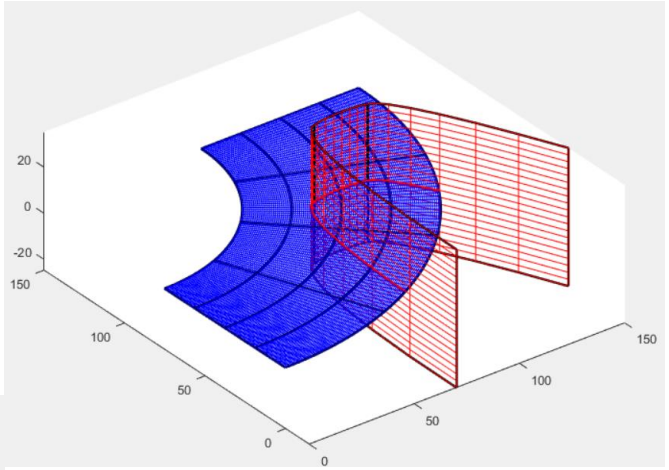


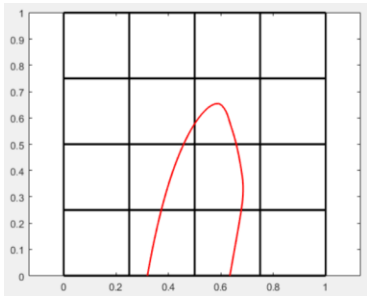
04.- EXAMPLES

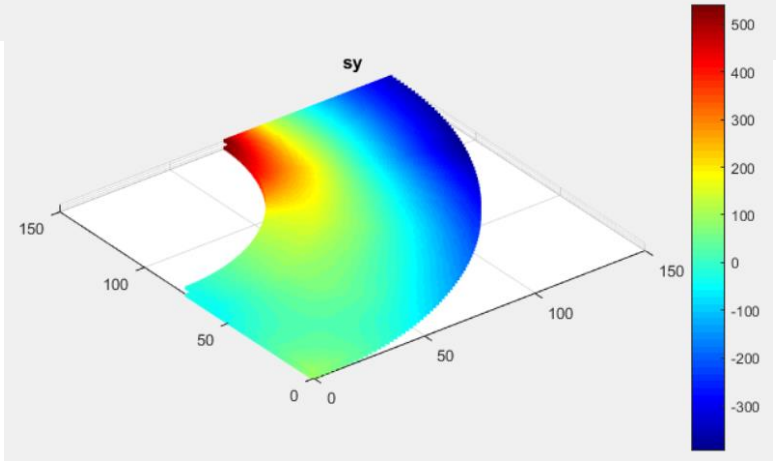
Trimming and displacement calculation example:

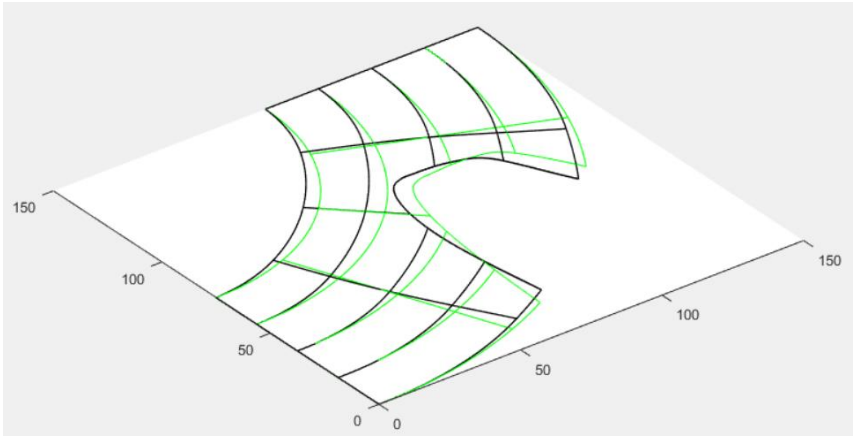
- Slotted washer quarter :











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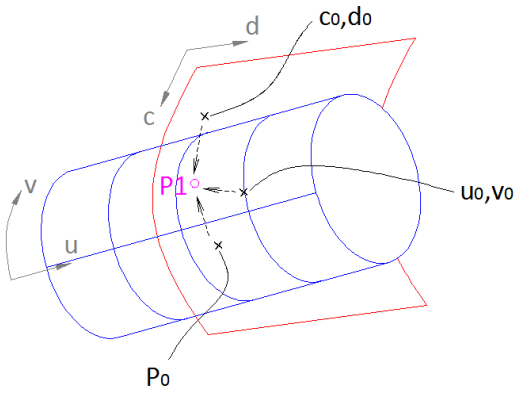
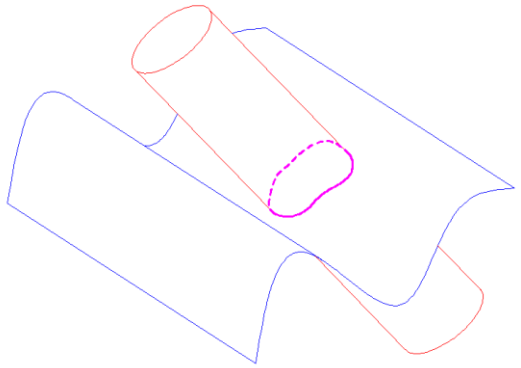
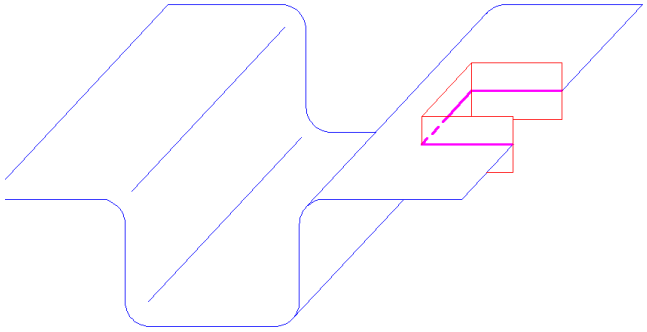
Algorithm to select the initial searching points



Allow trimming surface to be closed (simulate holes)



Non-derivable trimming surfaces



06.- POTENTIAL IMPROVEMENTS

Remove trimming curve dependency on step (step length selection)

THANK YOU FOR

YOUR ATTENTION

References

[1] Hughes TJR, Cottrell JA, Bazilevs Y. *Isogeometric analysis: CAD finite elements NURBS exact geometry and mesh refinement*. Comput. Methods Appl. Mech. Engrg. 194 (2005) 4135–4195.

[2] Cottrell JA, Hughes TJR, Bazilevs Y. *Isogeometric Analysis, Toward Integration of CAD and FEA*. Wiley, (2009).

[3] Xiao LH, Yuan DH, Xiang JZ, Liu JG, Zhou YC. *Residual stress in the cylindrical drawing cup of SUS304 stainless steel evaluated by split-ring test*. Acta Mech. Sin. (2016) 32(1):125–134

[4] Kim HJ, Seo YD, Youn SK. *Isogeometric analysis for trimmed CAD surfaces*. Comput. Methods Appl. Mech. Engrg. 198 (2009) 2982–2995

[5] Piegl L, Tiller W. *The NURBS Book. Berlin*. Springer-Verlag, (1996).