International Journal of Advanced Mechanical Engineering.
ISSN 2250-3234 Volume 4, Number 5 (2014), pp. 463-472

http://www.ripublication.com/ijame.htm

Automizing the Design of Francis Turbine Spiral Case

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Abstract

Currently the engineering design cycle time for the entire Francis turbine (H=169m, P=55.8 MW, Q=46.82 m^3/sec and N=300 r.p.m) design is around 3000 hrs. This includes the time taken for the development of assembly, outline and manufacturing drawings for all the components. Out of this, approximately 365 hours is spent on the design of Spiral Case assembly. Once the design cycle starts, the design engineers are working at 120% load to complete the design on time. As specific standard is not being followed properly, different designers design differently. Also the design and drawing creation are done simultaneously which is resulting in more design cycle time. The aim of this work is to design and develop an automated application using Unigraphics NX 3.0 and Knowledge Fusion, which will assist the users in creating new designs of Spiral Case as per the specification with help of user friendly interface. Thus automating the generation of design parameters, 3-D geometry and 2-D drawings of Spiral Case Assembly and its sub Assemblies as per the standards. This results in an overall reduction in the design cycle time for Francis Turbine Spiral Case.

Keywords: Assembly, Automation, Design, Knowledge Fusion, Spiral Case, Turbine.

1. Introduction

The major components of Francis turbine are
1.Spiral Case 2.Guide mechanism 3.Runner 4.Draft tube.

The way in which water is fed to the Reaction turbine blades is ingenious. Turbine efficiency is greatly increased if the entering water has a strong rotational motion or whirl. To provide such whirl, the water enters a tapered spiral chamber known as a scroll case or Spiral case, which curves right around the whole unit. Thus several studies have been conducted for improvement of this component design and reduction in design cycle time. Presently the Design Engineers at Hydro Turbine group manually design and validate the Spiral Case Design for correct design requirements. To achieve this goal with a lesser effort and a lower lead time Spiral Case Design Automation is developed. This application gathers necessary information from the user and interactively helps the user to generate the Spiral Case Design by taking care of all the Design Standards and Best Practices. The *Spiral Case Design Automation is* built on *Unigraphics/Knowledge Fusion (UG/KF)* environment that supports multi-standard compliance, automate the process of generating 3D models, manufacturing drawings from the 3D models.

2. Spiral Case Design Methodology

To determine the geometry design parameters needed for generation of spiral case concerns with below standard formulae.These formula has been automated for the generation of design parameters report.

2.1 Inputs to the Spiral Case

$\mathbf{R_c}$=Centroidal Radius of the Shell from the Spiral Case
$\mathbf{R_s}$=Radius of the Shell
$\mathbf{R_{st}}$ / $\mathbf{R_h}$=Radius up to the end of transient piece from the Spiral Case
$\mathbf{H_{st}}$=Height of the Stay Ring
N=Number of casing sections
*Type of **Material** considered with Factor of Safety.*
CT=Corrosion tolerance
P =Design pressure

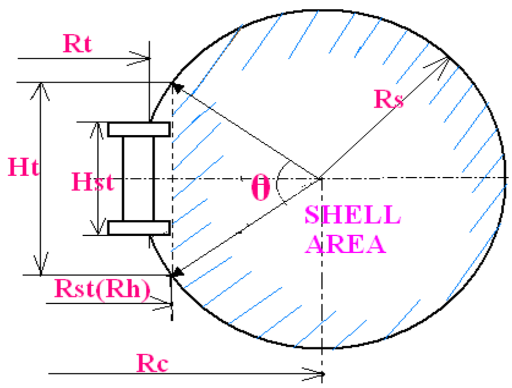

Fig. 1: Spiral Case Shell Section.

2.2 Area Calculation for Section 1

$r_c(1) = R_c$
$R_{(cs\text{-}st)}(1) = R_c(1) – R_{st}$
$R_s = D_s/2$
$R_t(1) = R_c - \sqrt{(R_s^2 – H^2_{st})}$
$R_{(st\text{-}T)}(1) = R_{st} – R_t(1)$
Theta $\theta(1) = 2\tan^{-1}(\sqrt{(R_s^2 - R^2_{(cs\text{-}st)})} / R_{(cs\text{-}st)})$
$Area(1) = (1/2)*(2*\Pi - \theta)* R_s^2 + (½)*R_s^2 *Sin(\theta)$.

2.3 Area calculation for Section 2 to Section N

Angle between consecutive sections is given by $\alpha = 360/N$

For the first section, angle from the center line of Spiral Case $\beta(1) = 0$

For the i[th] Section angle from center line of Spiral Case $\beta(i) = \alpha + \beta(i-1)$

Area of ith Section

$Area(i) = A(1) - [A(1) *\beta(i) / (2*\pi)]$; where i=2 to N;

For 'i' from 2 to N

$R_S(i) = R_S(i-1)* \sqrt{(Area(i)/Area(i-1))}$
$= [R_S(i-1) + H_{St}]/2$ (If $R_S(i) < H_{St}$)… ….. (1)
$\Delta R_S = abs[R_S(i-1) - R_S(i)]$ (2)
$R_C(i) = R_t + \sqrt{(R_S^2(i) - H_{St}^2)}$ … .(3)
$R_{(CS\text{-}St)}(i) = R_C(i) – R_{St}$ \ ... … (4)
Theta $\theta(i) = 2\tan^{-1}(\sqrt{[(R_S(i)^2)] - [R_{(cs\text{-}st)}(i)^2]} / R_{(cs\text{-}st)}))$ ….(5)
$Area(z) = (\Pi*[R_S(i)]^2 - ((1/2)[R_S(i)]^2 [\theta(i) - Sin\,\theta(i)]))$ …..(6)

If Area (z) is not equal to Area (i) within the tolerance of 0.00001 then recalculate $R_S(i)$as follows

New $R_S(i)$=Current $R_S(i) + (0.5*\Delta R_S)$.(If Area (i)> Area (z))

=Current $R_S(i) - (0.5*\Delta R_S)$.(If Area (i)< Area (z))

New $\Delta R = |$ Current $R_S(i)$ - New $R_S(i)|$

Repeat steps from (3) above with New $R_S(i)$ else Repeat steps from (1) above for next 'i '

2.4 Shell Plate Thickness

1. Select material →given σ_y or σ_u.
2. Enter Factor of Safety to determine $\sigma_{allowable}$

$\sigma_{allow} = (1/2)\sigma_y, (1/3)\sigma_y, (0.75)\sigma_y$ Or $(1/3)\sigma_u, (1/4)\sigma_u, (1/5)\sigma_u, (0.3)\sigma_u$.

Thickness of ith Section:

$T_{iz}(i) = (CT + (P* R_S(i)*Contact\ point(i)))/(\eta* \sigma_{allow})$

If calculation for thickness is considered at the contact point of spiral casing and transient piece then

$Contact\ point(i) = [R_H + R_C(i)]/[2* R_H]$

If thickness calculation is done at contact point of Spiral casing and Stay ring then

$Contact\ point(i) = [R_t + R_C(i)]/[2* R_t]$

T(i)=Next integer of $T_{iz}(i)$

3. Spiral Case Assembly Design Automation Process

Good user interface design can make a product easy to understand and use which results in greater user acceptance.UG NX 3.0 User Interface/ Styler is used for developing the user interface. The application is developed using UG / Knowledge Fusion or UG / OPEN API.

Fig. 2: UI Main Dialog.

3.1 Main Dialog

It states, once the user chooses to create / edit a design, the system will launch NX with this dialog up. If in *Fig. -UI Main Dialog* there are any errors, then **Apply** and **OK** buttons are made hidden. The user interface for all the above automated components will be as follows:

3.2 Foundation Assembly UI

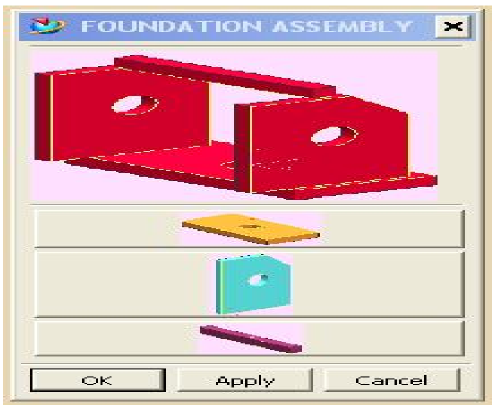

Fig. 3: Foundation Assembly UI.

3.3 Lifting Lug UI

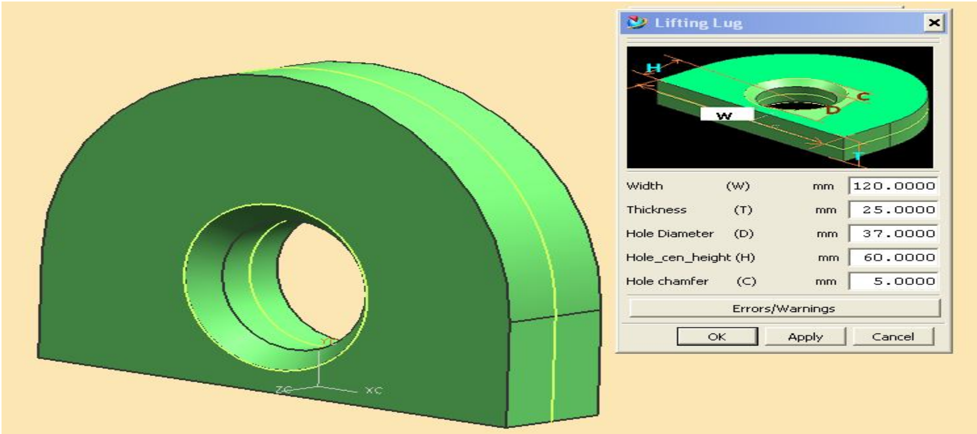

Fig. 4: Lifting Lug UI for Correct Design.

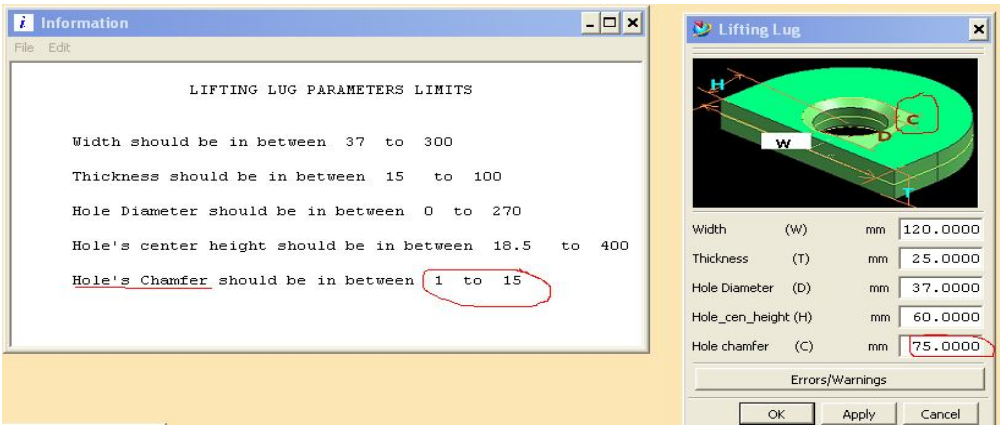

Fig. 5: Lifting Lug UI showing Design Limits for Error Design.

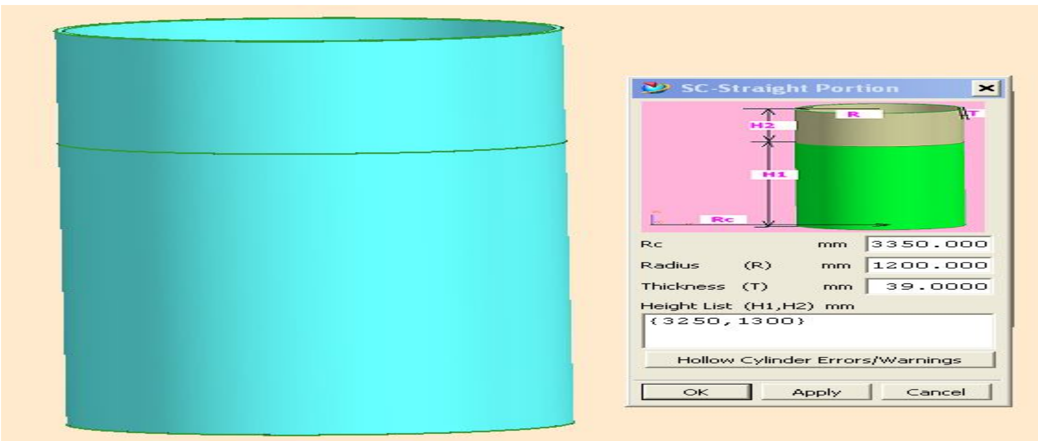

Fig. 6: Straight Portion UI.

3.4 Straight Portion UI
3.5 Spiral Case UI

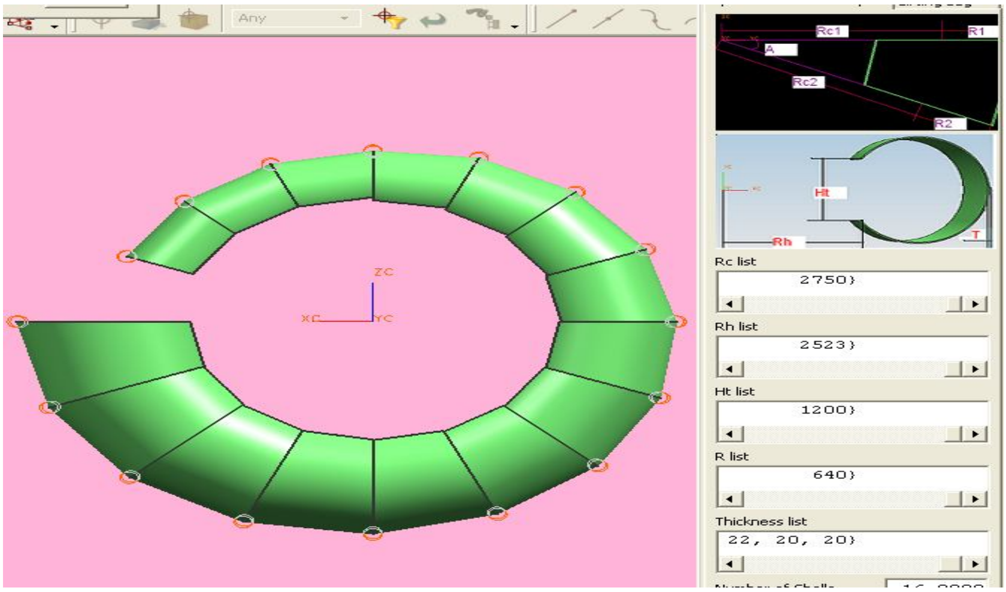

Fig. 7: Spiral Case UI.

3.6 Spiral Case Assembly UI

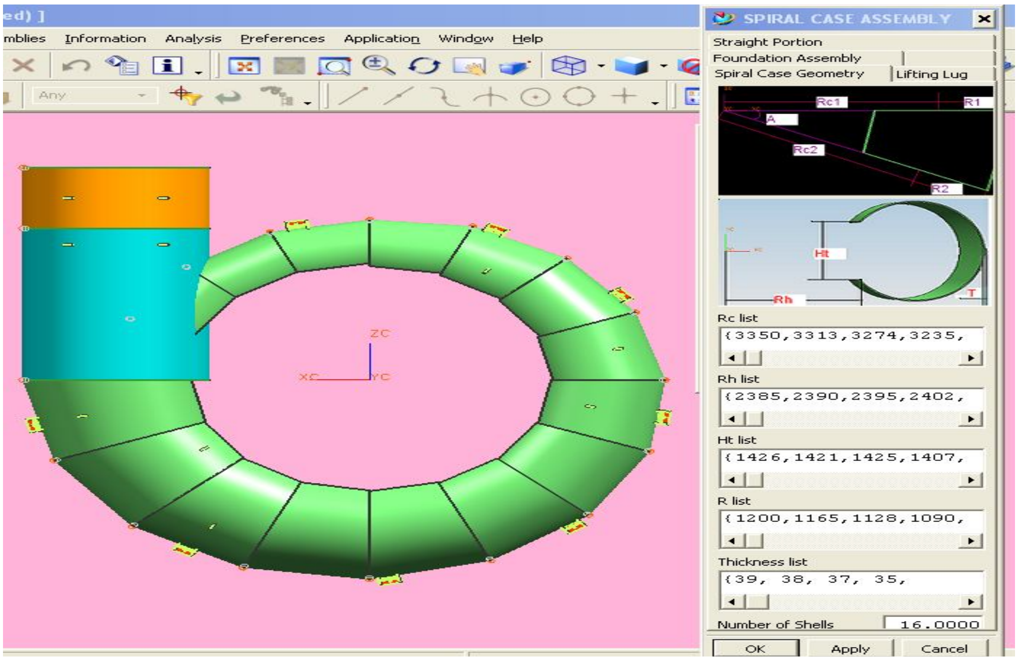

Fig. 8: Spiral Case Assembly UI.

4. Results and Discussions

4.1 Turbine Spiral Case Specifications:

Net head (H)=169 m
Output Power (P)=55.8 M.W
Discharge (Q) =46.82 m^3/sec
Speed (N)=300 r.p.m.
Spiral case Centroidal radius (R_c)=3350mm

4.2 Inputs to the Spiral Case Design

Centroidal Radius of the first Shell from the Spiral Case/ Straight pipe connected to Penstock **(R_c)** = 3350 mm

Radius of the first Shell/Straight pipe connected to Penstock (**R_s**) = 1200 mm
Radius up to the end of transient piece from the Spiral Case (**R_{st} / R_h**) = 2385 mm
Height of the Stay Ring **(H_{st})** =712 mm
Number of shell sections (**N**) =16
Factor of Safety **(F.S)**=1.333
Corrosion tolerance (**CT**)=1.5 mm
Design Pressure (**P**)=2.4 N/mm^2
Welding coefficient (**η**) = 0.95

4.3 Design Automation Results

4.3.1 Spiral Case Design Parameters Report:

Table 1: Spiral Case Design Parameters.

Shell Section	R_c (mm)	R_s (mm)	R_H (mm)	T (mm)	H_T (mm)
1	3350	1200	2385	26	1426
2	3313	1165	2390	25	1421
3	3274	1128	2395	24	1415
4	3235	1090	2402	23	1407
5	3193	1051	2409	22	1399
6	3150	1010	2417	21	1389
7	3104	968	2425	20	1379
8	3057	923	2435	19	1365
9	3006	876	2447	18	1348
10	2952	827	2459	17	1328
11	2893	774	2474	16	1302
12	2829	717	2493	15	1266
13	2758	658	2513	14	1221
14	2758	658	2513	16	1221
15	2758	658	2513	16	1221
16	2758	658	2513	16	1221

4.3.2 3-D geometry of Spiral Case Assembly and Sub Assemblies

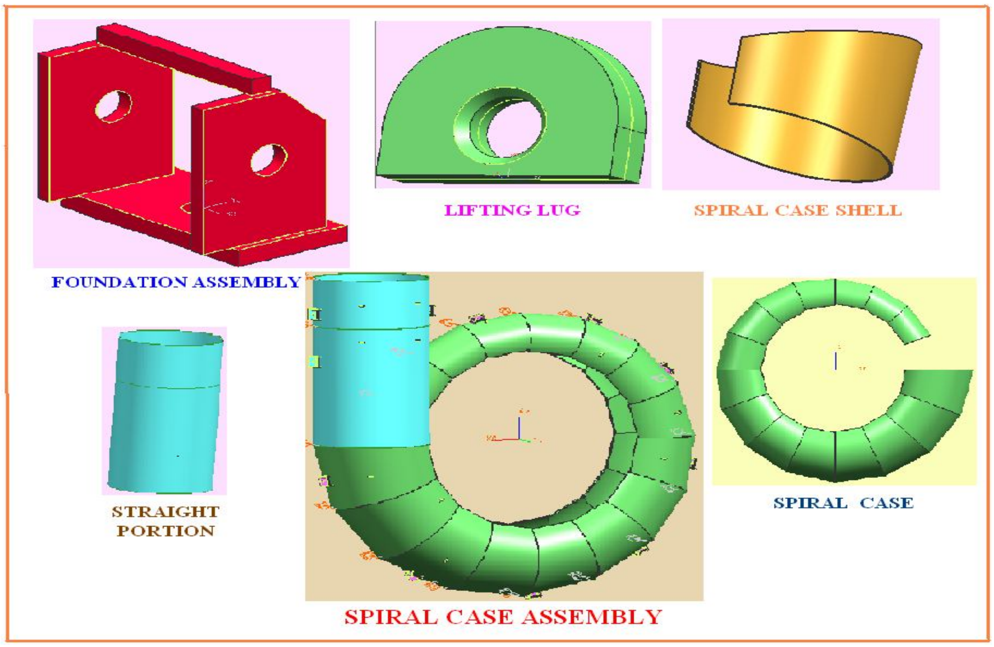

Fig. 9: 3-D geometry of Spiral Case Assembly and Sub Assemblies.

4.3.3 2-D drawings of Spiral Case Assembly and Sub Assemblies

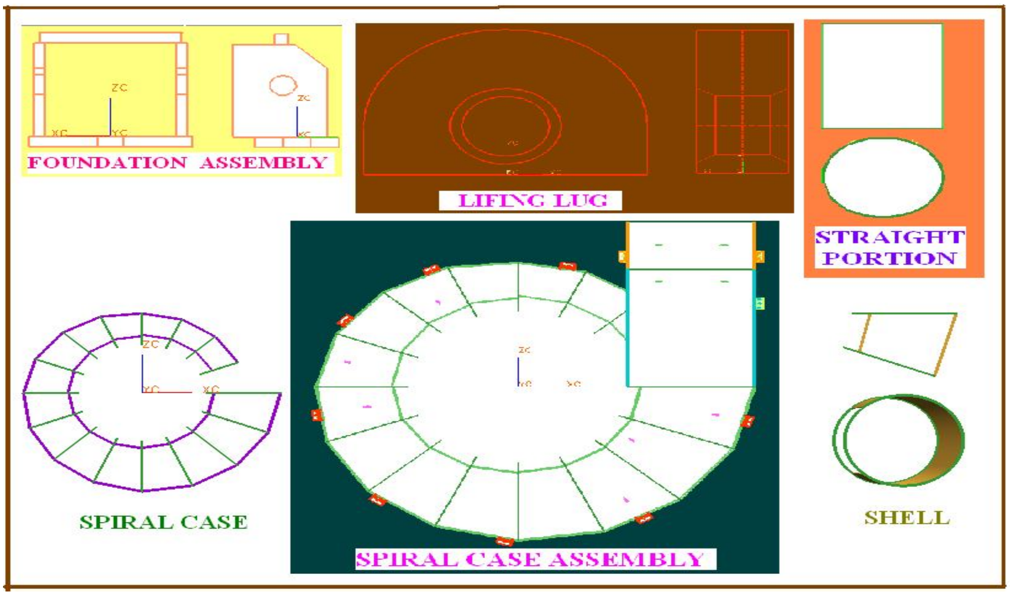

Fig. 10: 2-D drawings of Spiral Case Assembly and Sub Assemblies.

5. Conclusion

A Unigraphics based Knowledge Fusion tool automation application for Spiral Case design is developed to

1. Make use of one standard set of rules for the design
2. Develop User-friendly Interface for providing the inputs and reviewing the results.
3. Automate the Generation of Spiral Case design parameters Calculation report.
4. Automate the generation of 3-D geometry of Spiral Case Assembly and sub Assemblies.
5. Automate the creation of 2D drawings of Spiral Case Assembly and sub Assemblies.

The above aspects results in an overall reduction in the design cycle time for Francis Turbines by 65%.Thus the total time to design Spiral Case assembly in the to-be process can therefore be brought down to an estimated 160 hours in place of the current 365 hours.

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