Advanced Materials Manufacturing & Characterization Vol 3 Issue 1 (2013)

Advanced Materials Manufacturing & Characterization

journal home page: www.ijammc-griet.com

KBE approach towards design automation of Francis turbine spiral casing

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A R T I C L E   I N F O

Article history:
Received 22 Oct 2012
Accepted 26 Dec 2012

Keywords:
Spiral casing,
Design automation,
KBE,Unigraphics NX KF

A B S T R A C T

A knowledge based engineering (KBE) approach has been preferred over the traditional design approach which majorly relies on the expert designer who has to look over many requirements like specifications, Libraries of standard items, physical laws, material properties, best practices, design approaches and results in KBE Approach, a knowledge base is leveraged to automate the iterative design process. Similar approach has adopted to design and develop an automated application using Uni-graphics NX and Knowledge Fusion, which will assist the designers in creating new designs of Spiral Case as per the requirements. Validation of the design is also done. This results in an overall reduction in the design cycle time for Hydro Turbine by 65%.

Introduction

The Francis turbine shown in Fig. 1 is a reaction turbine, which means that the working fluid changes pressure as it moves through the turbine, giving up its energy. A casement is needed to contain the water flow. The turbine is located between the high pressure water source and the low pressure water exit, usually at the base of a dam.

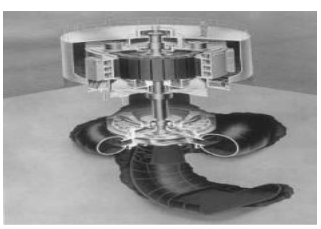

Fig. 1 Francis Turbine

Major Components of Francis Turbine:

Runner is the rotating part of the turbine that converts kinetic energy of falling water into mechanical
energy through principles of impulse and reaction, or a mixture of the two.

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• Doi:http://dx.doi.org/10.11127/ijammc.2013.02.057

Spiral case and stay ring assembly is the setup to in take water and guides the flow into the guide vanes located just prior to the Runner.

Head Cover is the component which acts as a top cover for the hydro turbine assembly preventing the leakage of water in the upward direction and also functioning as the support for the Guide Vane operating mechanism, guide bearing and shaft seal.

Bottom Ring is the component which acts as a bottom cover for the hydro turbine assembly preventing the leakage of water in the downward direction and also functioning as the support for the guide vanes.

Discharge Ring is the component which exists immediately below the bottom ring in case of turbine downward disassembly. This component derives its name from its position i.e., the discharge portion.

Guide Vane operating mechanism consists of guidevanes, links, arms and operating ring which are driven by a servo motor setup. This will result in the rotation of the guide vanes which is required for maintaining high efficiency of the turbine even for fluctuating water inflow conditions.

Shaft Seal is the component which will prevent the leakage of water in the upward direction.

Guide Bearing is the component which will provide a support for the shaft during its rotation.

Upper Draft Tube is the component that comes immediately above the draft tube.

Draft tube is a water conduit. This can be straight or curved that maintains a column of water from the Runner outlet and the downstream water level.

Turbine Pit Liner is the component which will function as the border for the turbine pit and also contains the outlets for the piping

The hydraulic research of the water passage through the spiral case to stay vanes becomes very important in diminishing the losses of the flow and the angle .Hence the shape of Spiral Case and stay vane cascades are carefully designed.

Unigraphics knowledge fusion:

In a *Traditional Organization* the Product Design Process shown in Fig. 2 is completely dependent up on the Expert/designer who has to look over many requirements like specifications, Libraries of standard items, physical laws, material properties, best practices, design approaches and results. But too many manual interventions results in increased Data loss, drop in-quality and repetition of tasks. Also the design errors were identified very late in the process.

Thus this results in a Non-standardized product with an increased cycle time. Here the output is extremely designer dependent (i.e., Too much dependence on the experience and expertise of the designer).So losing an expert designer means losing knowledge.

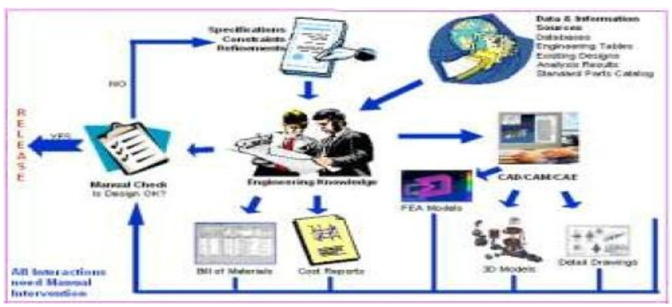

Fig. 2-Traditional Organization Product Design Process

Thus the need is to automate and seamlessly integrate all the activities involved with no data loss .It can be achieved by using K.B.E.

Knowledge based engineering (kbe):

Knowledge Based Engineering is fundamentally about re-use of prestored design knowledge as shown in Fig. 3. It concerns being able to take advantage of any experience, expertise and other information relevant to each phase of the engineering life cycle of an end user product. These knowledge bases, as they are collectively known, can exist in many forms such as spreadsheets, handbooks, engineering formulas, proprietary software, or in human judgment, such as rules of thumb. Being able to create and reference such knowledge bases and make them readily available as an aid to the engineering process constitutes Knowledge Based Engineering.

KBE is the key to being able to answer questions of some significance that traditional CAD systems to date have not been capable of addressing such as:

[1] "What was the rationale behind this design?"

[2] "Have any design constraints been violated?"
[3] "How much will this product cost?"
[4] "Can this part be manufactured?"
5) "Will this part meet its performance goals?"

All these questions are, potentially, answerable with precision. Since the information required or the means to obtain it exists, although distributed in various forms throughout multiple organizations.

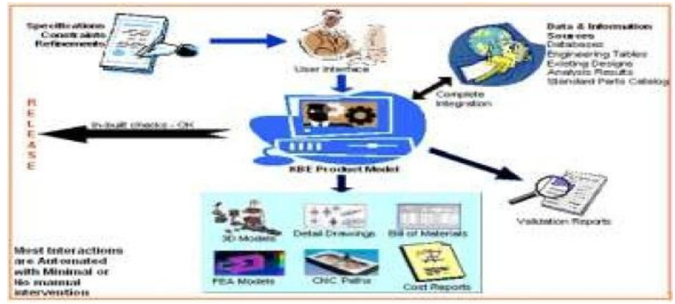

Fig.3-Knowledge Based Organization using KBE

Benefits of using a kbe system:

1) Capturing engineering expertise

2) Improving quality
3) Lowering product costs
4) Promote Standardization
5) Identifying errors very early in the process
6) Integrating catalogs and databases
7) Absolutely no loss in data
8) Generating performance reports.
9) Integrating analysis tools into the design process.

Knowledge fusion:

The Unigraphics NX Knowledge Fusion language is an interpreted object-oriented language that has been designed to permit an end-user to easily add engineering knowledge to the task at hand by the creation of rules, which are the basic building blocks of the language. The language is declarative, rather than procedural, which means that the rules can be written without regard for order. The UG/KF system determines the correct rule firing sequence driven by the dependencies between the rules. Additionally, the language has the capability to access external knowledge sources, such as databases or spreadsheets, and to interface to other applications such as analysis or optimization packages.

Rules can also create geometric modeling features and expressions, utilize UDF's, and build assemblies. UG/KF supplies a rich set of Unigraphics NX class libraries. We can write the rules that create instances of particular classes. We can also create your own classes and are able to extend the Unigraphics NX data model.

It is important to understand that the KBE language and the interactive system both create the identical set of Unigraphics NX objects. Both the language specification of an object and all information made available through since both are merely different ways of observing the unique underlying Unigraphics NX object model description.

If an object is edited interactively, say a modeling dimension, then the language description automatically reflects that change; the reverse is also true. Control is given to us over the impact of interactive edits when the object has a corresponding rule. The setting of an attribute on a rule-by-rule basis, lets us reject any edit. Only a deep integration strategy can make these behaviours possible.

Spiral case design methodology:

In order to provide maximum flexibility and control to design Spiral Case Design and also to generate the drawings with minimal amount of rework, the design process has been split into a two-stage process

Basic Designing Stage:

During this stage, the designer is allowed to enter input data, generate and validate SC geometry in a repetitive fashion. This would allow the designer to try out various parameters and options until the best possible configuration is achieved. During this stage, the designer can also generate various reports.

Detail Design Stage:

Based on the design parameters from Basic Designing Stage, the application will choose appropriate templates. These templates will contain relevant 3D and 2D details.

This gives an idea , to determine the geometry design parameters needed for generation of spiral case concerning with standard formulae.

Assumptions:

1. Outside diameter of the Stay Ring is constant throughout all section i.e. Outer edge of Stay Ring is circular.
2. **2.** Distance of contact point of Spiral casing and Stay Ring from centre of SC is constant for all the Section.
3. Casing divided angle for section will remain constant and is given by α =360/N where N is the number casing section.

The following figure Fig. 4, shows the typical spiral case shell section.

Inputs to the Spiral Case:

Rc =Centroidal Radius of the shell from the spiral case

R_s =Radius of the shell

Rst / R_h=Radius up to the end of transient piece from the spiral case.

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

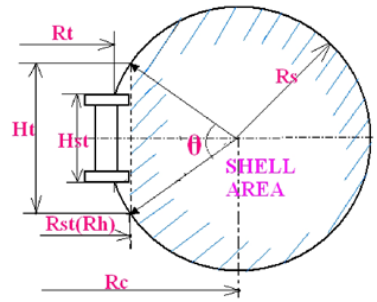

Fig. 4-Spiral Case Shell Section

Area calculation for Section 1 :

Rc(1) = Rc

R (cs-st) (1) = $R_c(1) - R_{st}$

R_s = D s/2

R_t (1) = Rc - $\sqrt{(Rs^2 - H^2st)}$

R(st-T) (1) = $R_{st} - R_t$ (1)

Theta θ(1) = 2tan $^{-1}(\sqrt{(Rs^2-R^2(cs-st))}$/ R(csst)

Area(1) = $(1/2)*(2*\Pi-\theta)*Rs^2+(½)*Rs^2$ *Sin (θ).

Area calculation for Section 2…Section N:

Angle between consecutive sections is given by □□□ 360/N

For the first section, angle from the center line of Spiral Case □(1) □ 0

For the ith Section angle from center line of Spiral Case □(i) = □ + □(i-1)

Area of ith Section

Area (i) =A(1)- [A(1) *□(i) /(2*□)]; 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)

Δ 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-St) (i) = R_C (i) – R_{St}\………………… (4)

Theta θ (i) = 2tan $^{-1}(\sqrt{[(R_S(i)^2)]-[R_{(cs-st)}(i)^2]})/ R_{(cs-st)})$ ….(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) with in 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 ΔR = $|$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 '

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) σ_y , (1/3) σ_y, (0.75) σ_y

Or (1/3) σ_u., (1/4) σ_u., (1/5)σ_u, (0.3) σ_u.

Thickness of i^{th} Section:

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

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 Tiz (i)

To achieve this goal with a lesser effort and a lower lead time, Spiral Case Design Automation Tool is developed. This application gathers necessary information from the user and interactively helps the user to generate the Spiral Case Design taking care of all the Design Standards and Best Practices.

Input/Output:

All the inputs/outputs will be in metric units. And user is allowed to override default parameters and certain calculated values to control the design.

The data required for the Design of the Spiral Case Design Automation Tool will be created in Microsoft Excel spread sheet . This will ensure that the application will work with updated and correct values, when the values of the data change, without having to change the code to access the new values of the data.

The Spiral Case Design Automation Tool results in calculation of spiral case design parameters as shown in Table 1, generation of visualization geometry (i.e. 3-D models) as shown in fig.7 and generating the manufacturing drawings (i.e.2-D drawings) as shown in fig.8 from the visualization geometry.

Table.1 - Spiral Case Assembly Default InputData Sheet

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

Design validation:

Using Unigraphics NX in-built analysis tool design validation has been performed.

Allowable stress (σ_{allow}) = (σ_Y) / (F.S)

= 482.633/1.333

= 362.065 N/mm^2

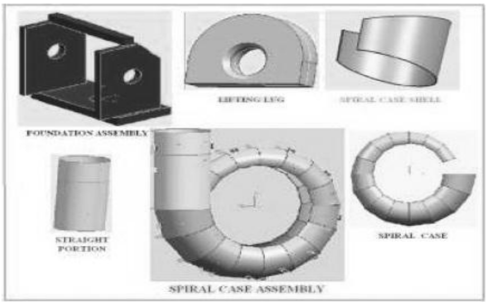

Fig. 7-- 3-D geometry of Spiral Case Assembly and Sub Assemblies

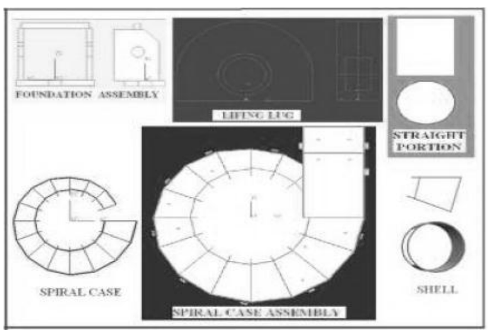

Fig. 8--2-D drawings of Spiral Case

The maximum induced stress in Shells which is obtained through UG structural analysis is compared with Shell material allowable stress is as shown in Table 2.

The above aspects results in an overall reduction in the design cycle time for Hydro 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. The Automated Application developed doesn't need Expert/designer for product design process. It prevents too many manual interventions which results in data loss, drop in quality, repetition of tasks. The design errors were identified very early in the process.

This results in Standardized product design with reduced cycle time and lowered product costs.

The maximum induced stresses in shells are less than allowable stress value. The design is proved to be safe.

Table 2 Spiral Case Design validation

Shell Section	R_c mm	R_s mm	R_H mm	T mm	H_T mm	Maximum Induced Stress	Allowable Stress
1-2	3350	1200	2385	26	1426	322.8	362.065
2-3	3313	1165	2390	25	1421	319.1	362.065
3-4	3274	1128	2395	24	1415	309.7	362.065
4-5	3235	1090	2402	23	1407	302.7	362.065
5-6	3193	1051	2409	22	1399	295.2	362.065
6-7	3150	1010	2417	21	1389	284.5	362.065
7-8	3104	968	2425	20	1379	272.2	362.065
8-9	3057	923	2435	19	1365	265.7	362.065
9-10	3006	876	2447	18	1348	238.7	362.065
10-11	2952	827	2459	17	1328	219.5	362.065
11-12	2893	774	2474	16	1302	205.8	362.065
12-13	2829	717	2493	15	1266	169.7	362.065
13-14	2758	658	2513	14	1221	61.1	362.065
14-15	2758	658	2513	16	1221	51.9	362.065
15-16	2758	658	2513	16	1221	51.9	362.065

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