OPTIMIZATION OF CIRCULAR-GROOVED SQUARE CAVITY LABYRINTH SEAL AND CFD ANALYSIS BASED ON ANN MODELLING

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ABSTRACT

Labyrinth seals are used to perform sealing around the rotating Parts of various mechanical machineries. Its work is to minimize escape of fluid essentially gases from high pressure area to low pressure area this is process by building of series of labyrinth teeth which are arranged to provide a close clearance gap between the stator and rotor components of the machine, this may cause a pressure drop occurs across each gap. The main aim of this study is to discuss the Optimization of Circular-Grooved Square Cavity Labyrinth Seal and CFD Analysis Based on ANN Modelling. The methodology for developing two semi-theoretical-semi-experimental formulae and linking them with the ANN technique for obtaining the optimal CSLS is described in this paper. It is concluded that the CFD analyses of the optimal seals confirmed the improvements caused by the cavity shape and captured performance parameter trends. The P_r *values of 1.6 are found in the best circular-grooved square and triangular cavity labyrinth seals.*

Keywords – CFD, labyrinth seal, CSLS, ANN modelling, etc.

1. INTRODUCTION

The operating and execution of a couple of fluid flow frameworks is impacted by the essence and pace of leakage flow through annular sections at specific emplacements used in analysis of operations and applications. Sealing is a crucial factor in most aspects intended to prevent the fluid used by a machine for minimizing leakages. This role of mechanical seals contributes to join systems or mechanisms together by preventing leakage of environmental contamination, saving energy through improved machine operating efficiency, and machine safety. For effective sealing purpose the face materials where the stationary ring and the rotary ring is always resiliently mounted and spring loaded. To accommodate effective sealing, it is inevitable to control the clearance in between lapped faces of seals in the order of micrometers to prevent leakage as effective sealing of a rub system confide on more than just the size and geometry of the clearance gap. For instance, the engine cylinder needs to work in a without leakage environment to restrain loss of energy. In multi-sort out turbo machinery, the leakage flow between stages ought to be reduced for achieving better effectiveness. In the turbo siphon of a cryogenic rocket engine, the leakage flow over the oxidizer and fuel streams must be held a determined good way from to check accidents. In a fluid metal nuclear reactor, leakages and cavitation powers should be irrelevant at essential locations.

1.1 Labyrinth Seals

A labyrinth seal is provided for sealing the annular aperture between the stator and the rotor of a high-speed gas turbine or steam turbine.

The labyrinth seal includes a profusion of sealing strips which are organize in series in the axial direction and fastened on the stator and project into the interfaculty of openings.

Labyrinth seals are tremendous non–reaching seals in turbo machinery, for example, turbines, generators, compressors, and pumps. They meet the sealing prerequisite, while certain leakage is consented. This work concludes and centers on the labyrinth seals in fly motors with gas as the working fluid.

1.2 Circular-Grooved Square cavity Labyrinthine Seal (CSLS)

The operation for labyrinth seals superior to anything the annular seal determines the seal section to be changed up to the point that adequate additional flow obstruction is obtained. This supported the option of amalgamating labyrinths of different shapes with discrete leakage mass flow rates. It divulges that the labyrinth seal acquiesce a lesser leakage for a given weight drop extent or then repeatedly for a specific leakage flow the related weight drop is higher for arrange of fluids like liquids, steam and air.

A round notched labyrinth seal usually called circumferentially-scored or straight through labyrinth seal which is constrained in its capability to function with a wide range of fluids due to its limited capacity to centrifugally push the lubricants back into the controlled fluid cavity which contains exchange bits of straight annulus and ring formed holes of exact geometries like triangle, square, etc. Therefore, in accordance of inspected further, it revealed that it can only handle a definite volume of lubricating fluid in the controlled fluid cavity and it requires high revolving speeds to seal adequately when sinusoidal-furrowed labyrinth seal and helical-notched labyrinth seals (generally called screw seals) have to form cavities separately in layered and helical styles. This entire geometry of labyrinth profile and configuration utilize a critical impact on the seals' P̂. A round notched square depression labyrinth is seen in Fig.1

This section expeditiously analysis the elementary ideas in the plan of labyrinth seals, by using evaluate the three-dimensional CFD simulations and Computational Solid Mechanics (CSM) with accentuation on subside through flow work, and numerical methods of FSI.

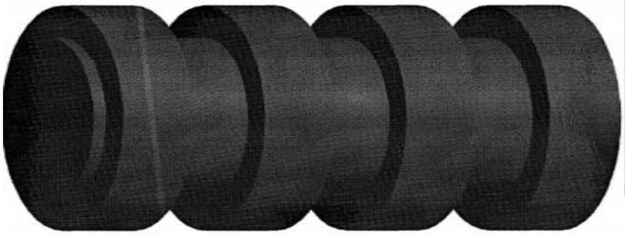

Figure 1: Circular-grooved square cavity labyrinths

1.3 ANN

The ANN idea, albeit almost 50 years of age is getting widely applied in engineering practice during the past two decades, from an analogy with human cerebrum behavior, ANN can repeat a process from preparing models viz. neuro computing instead of numerical model based customized computing. It reproduces human functions, for example, gaining as a matter of fact, summing up from past to new information and abstracting fundamental characteristics from inputs. It is identified with artificial knowledge, AI, parallel processing, measurements and guess calculations and isbest fit to tackling issues that are too hard to even think about solving by conventional computational methods.

ANN can model complex information connections. Because of its topological structure, it can adaptively take in nonlinear mappings from input to output space when the network has a huge database of earlier guides to draw from. It maps input to the output by gaining from the provided preparing information. It is utilized as a device for discovering non-clear, non-straight conditions between information, figure 2 demonstrate a typical network.

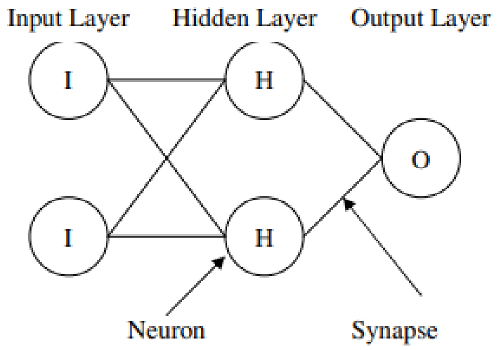

Figure 2:SchematicofatypicalANN

ANN is made out of a few elementary interconnected processing elements working in a parallel manner, the recognitions. The essential engineering of ANN comprises of layers of interconnected processing units called neurons comparable to the dendrites in the biological neuron, which change an input vector into an output vector. Neurons empower ANN to be an output giving black box to various inputs. The output is acquired by processing the weighted whole of the inputs with a transfer capacity called actuation work, which as a rule is a nonlinear monotonic capacity.

Neurons without antecedents are called input neurons and establish the input layer. Every other neuron is called computational units. A non-void subset of the computational units is indicated as the output units. Every computational unit, which are not output neurons, are called shrouded neurons. Every interconnection between two neurons has a related weight factor and inclination that can be balanced by utilizing a proper learning calculation talked about later.

2. LITERATURE REVIEW

Artur Szymanski et al. (2019) - In this present work author discuss above overall efficiency and rotor stability for turbo-machineries in case of secondary flows for checking leakage flow. Further author explained with reference regarding effect of number of teeth, Reynolds number, the gap size, and the pressure ratio in consideration of efficiency for by a two-dimensional steady-state CFD study. For this study six number of seals configurations were examined with parameters straight knives with different gap size.

Eng, and Budea, Sanda et.al (2015) this article alludes to the consequences of trial research with respect to the thick fluid flow through sealing labyrinths of turbo machines. This labyrinth can be met both at the interstice among rotor and lodging, and in the zone of the interstice of the adjusting circle. Inside the exploratory inquiries about, fluid flows through the labyrinths at various Reynolds numbers were envisioned, pressure varieties along the length of the labyrinth and increment in pivot speed of the versatile ring were broke down. The trial results have to a great extent covered the numerical ones, affirming that the best geometry for the labyrinth with puzzles is the one with equal sizes for the channel's profundity and width.

Sanda BUDEA et al. (2014) - In this work author analysis upon volumetric efficiency of turbo machineries with considering laminar viscous fluid flow in order to design an effective labyrinth seal. In present work author considered ANSYS fluent and Computational Fluid Dynamics calculation to design effective seal. This consideration is done through flow spectrum, tangential and axial velocities and leading to the conclusion of best geometry for labyrinth.

Guo, Y. and Zhang, Y. and Li, J. (2008) The flow field of a trapezi form labyrinth screw pump for which the string number of the stator was twice that of the rotor has been mimicked utilizing the Computational Fluid Dynamics software Fluent. Investigation of the flow attributes, including the velocity and pressure fields, demonstrated that the fluid in the field of the stator is dependent upon huge unsettling influence, and that the velocity and pressure inclinations shift extraordinarily along the course ordinary to the divider.

Dereli, Yilmaz (2004) in this work, the gas flow in the straight-through labyrinth seal is contemplated. Leakage flow rate and pressure disseminations are determined by utilizing Neumann Modified Method and circumferential velocity appropriations are determined by utilizing Moody's Friction-Factor Model. Results are contrasted with different papers.

3. RESEARCH METHODOLOGY

The requirement for this exploration rashes because of the failure of the available seals and common cone like valve in gathering the prevalent concentrations under the constrained firm conditions, furthermore a significant part of the time, fluid flow through labyrinth seals and labyrinth-included valve plans are not pleasing for informative treatment. These edges deduce adequate degree for finishing broad assortment of research examinations on the effects of progressively current labyrinths on seals and cone moulded valve, affirmation of their discharge and cavitation flow characteristics and affirmation of their ability in gathering the foreordained mentioning essentials.

Use of flow discriminations and available speculative models outline the hidden periods of the labyrinth seal investigate framework. In perspective on the encounters grabbed, a couple of semi theoretical semi exploratory formulae including increasingly current coefficients are proposed to be produced. One beside the other usage of FEA/CFD based numerical assessments and exploratory examinations shape the major subject of the examinations. For the upgrade of helical-grooved square pit labyrinth seals, CFD and test examinations would be made on a couple of such seals. Using the got data pool, a weight drop condition would be acquired empirically using backslide assessment. This surrogate condition is mooted for streamlining helical-grooved square depression labyrinth seal geometry by using GA strategy.

3.1 Optimization of Labyrinth Seals

Improvement of labyrinth seals includes any appropriate process fit for choosing an unrivaled plan dependent on a pre-characterized criteria viz. greatest pressure drop. Enhancement issues can be named single or multi-dimensional. An improvement issue is single dimensional when just a single parameter is shifted. The equivalent is named multi-dimensional if more than one parameter is differed. The latter is appropriate in the present work.

Upgrading the geometry of the labyrinth seal to verify the most extreme pressure drop for a specific leakage flow rate in a given length of seal merits more consideration. Some exploratory information recommends the presence of an ideal pitch and the blade tallness didn't have a major impact as did the cavity width for compressible fluid seal. Morrison et al. noticed that the quantity of throttling is the most significant factor in planning a labyrinth seal.

Enhancement of labyrinth seal emerges because of the everlasting exchange off between the quantity of throttling and active energy carryovers. The advancement of labyrinth seal depends on the way that it is expected to verify a balance between making the pitch as huge as conceivable to diminish the remainder of motor energy and making the pitch as little as conceivable so as to get the most extreme number of throttling over a given length. The size and state of the labyrinth seal cavity influences the quality of the vortex and whirlpools which disperse the dynamic energy giving from every tooth into inner energy.

In light of the prior, the present investigation visualizes the utilization of semi hypothetical semi trial model based empirical formulae to assess Pr for fluid flow through CSLS. Utilizing the test information pool of CSLS, Artificial Neural Network (ANN) models are made utilizing the business MATLAB bundle. The ANN model in relationship with these formulae can recognize the ideal seals. Such modeling of pressure drops through water driven labyrinth seals could likewise help in improving the structure methodology of seals.

3.2 Semi Experimental Modeling of Liquid Flow Through CSLS

Nikitin and Ipatov utilized an empirical formula while considering leakage of oil-based fluids through labyrinth seals having rectangular/triangular cavities. Idelchik and Fried had given formulae to fluid flow through trapezoidal cavities. In spite of the fact that the methodology pursued here would be on comparable lines, due considerations will be given to the nature of flow example existing in the square and triangular cavity labyrinth seals managed here. Since the labyrinth seal issue doesn't fit total expository conceptualization, the created models will contain obscure values of resistance coefficients requiring the help of test information for their estimation.

The CSLS geometries individually, one pitch length of a labyrinth seal includes a straight annular entry and a cavity chamber partition. Fundamentally, the Bernoulli's condition would represent the losses occurring in the seal. The pressure drop happening in the straight annular section of the labyrinth seal can be determined with the assistance of Equation 1.

$$\Delta p_{annular} = \frac{\omega f l V_1^{2}}{2g(2c)} \qquad (1)$$

Where $Re = \frac{\rho V_1 (2c)}{\mu}$.

The value of the Darcy-Weisbach friction factor f is calculated by using the Blasius formula:

$$f = 0.316\, Re^{-0.25} \qquad (2)$$

The labyrinth cavity pressure loss is influenced by a few factors like the viscosity of the fluid, cavity geometry, and level of turbulence, flow heading and quality of the cavity vortex, boundary and shear layers created, nearness of vapor bubbles assuming any, and so forth. Finding an exact explanatory expression is inconceivable in light of the mind-boggling nature of cavity flow. The multifaceted nature is additionally expanded because of transitional impacts and turbulence showed during separation at the main edge, free shear layer and reattachment at the trailing edge.

The flow condition after the bay to the seal would not be completely created. Chochua et al. demonstrated that flow can turn out to be completely created after around 30 % of the seal length. They showed that when the flow turns out to be completely built up the profiles of mass flux and non-dimensionalturbulent dynamic energy and eddy scattering rate become unaltered.

Villasmil et al. have demonstrated that relying upon Reynolds number and cavity size, the flow can accomplish the completely created condition subsequent to disregarding a couple of cavities. Presently, a streamlined hypothetical methodology is given as portrayed beneath:

The loss of head because of an unexpected extension for flow through a pipe is given as,

$$h_e = \frac{(V_1 - V_{2e})^2}{2g} \qquad (3)$$

Where, V_{2e}isthe average velocity downstream of the abrupt development and V1 is the normal velocity in the annulus.

In the event that it is imagined that the entire leakage flow extends and goes into the cavity, at that point the imaginary or virtual cavity velocity V_2can be calculated as:

$$V_2 = \frac{Q}{\frac{\pi[D^2 - (D - 2d)^2]}{4}} \qquad (4)$$

Where, *D* is the maximum OD of the labyrinth, *d* is the depth of labyrinth cavity and *Q* is the volumetric leakage flow rate.Consider the head loss due to sudden contraction for flow through a pipe is given as:

$$h_c = \frac{K V_1^2}{2g} \qquad (5)$$

For flow through funnels, the entrenched value of the coefficient of withdrawal K for valves, elbows, and so forth is around 0.5. General values of K for labyrinth seals are inaccessible, since the division of leakage that agreements from the cavity before entering the following notch is obscure. A feeble vena contracta is framed at the channel district of the following straight annular segment. Thinking about the general seal geometry, there will likewise be some channel and leave losses which are normally little. In this way, the losses related with the vortex created inside every cavity would be the significant wellspring of head loss.

In such manner, Chochua had recognized a comparable marvel of head loss, while Arghir et al. had examined about an 'illuminated inertial lift' impact. Villasmil et al. have reasoned that divider shear stress at the straight annular part assumes an optional job and a steady mean flow distribution zone inside every cavity could prompt bigger rubbing factors and higher pressure drops.

In view of the above thinking, a general expression can be formulated to decide the cavity vortex pressure loss in analogy to the Eqns. furthermore, the pressure difference formula for a constrained vortex, accepting that little amounts of pressure losses brought about by the abrupt constriction/extension are guzzled inside it and the impact of gravity is unimportant.

$$\Delta p_{cavity} = K_v \rho (V_1^2 - V_2^2) \qquad (6)$$

Where, Kv is the vortex loss coefficient for CSLS, V1 is the average velocity in the annulus and V2 is the virtual cavity velocity term.

The virtual cavity velocity term has been expected to deal with the cavity/vortex size and speed of the vortex created inside the cavity of CSLS. Presently, the all-out pressure drop over length l for leakage flow through a static, fluid labyrinth seal is gotten by consolidating the Eqns. prompting the last structure:

$$\Delta p = \frac{\rho f Z a V_1^2}{4c} + K_v Z \rho (V_1^2 - V_2^2) \qquad (7)$$

Here,

$$Z = \frac{l}{p} = \frac{l}{a+b} \Rightarrow a = \frac{l}{Z} - b \qquad \text{——} \quad (8)$$

Where *a, b* and *Z* are the cavity width, length of the straight annular portion and number of grooves over the length of the seal respectively.

Now, the Eqn. is recast as,

$$\Delta p = \left(\frac{\rho f Z \left(\frac{l}{Z} - b \right) V_1^2}{4c} \right) + K_v Z \rho (V_1^2 - V_2^2) \qquad (9)$$

Or,

$$\Delta p = C_1 - C_2 Z + C_3 K_v Z \text{, for CSLS} \qquad (10)$$

Where,

$$C_1 = \frac{\rho f l V_1^2}{4c}, C_2 = \frac{\rho f b V_1^2}{4c} \text{ and } C_3 = \rho (V_1^2 - V_2^2) \qquad (11)$$

The vortex loss coefficient Kv in conjunction with the virtual cavity velocity V2 structures the arrangement of core parameters for portraying the present hypothetical model for CSLS. Since the values of Kv for a specific labyrinth seal must be resolved utilizing broad test/computational pressure drops, the above model basically constitutes a semi-hypothetical methodology.

Likewise, it very well may be seen that a solitary coefficient correlation for foreseeing the leakage has been formulated utilizing Kv, rather than two coefficient correlations generally accessible for compressible flow through labyrinths. Since the maximum value of clearance c and least length of the straight annular segment a for the seals examined so far are 0.5 mm and 1 mm separately, the base (a/c) ratio is 2. Since this value is higher than 1.6, the stream trailing the vena contract would soon reattach to the walls of the straight annular part. Presently, the related losses are genuinely constant and no extra coefficient may be required.

Figure 3 presents the variation in the trial values of the vortex loss coefficient Kv, assessed utilizing Equation for all the five CSLS tried. Nikitin et al detailed that the nearby resistance coefficient diminishes steeply for expanding Re in the turbulent flow system over the basic Re value of around 2000. The vortex loss coefficient Kv of the present work interestingly, is found to delicately and almost directly drop against Re for all the labyrinth seals tried. Its values are prevalently influenced by the geometry and flow design inside the cavity.

The expanded cavity size of LS3 over that of LS1 having b = 2 mm, has likewise prompted higher values of vortex loss coefficients as observed in Figure 3. By and large, the values of Kv have expanded as the cavity size increments. A nitty gritty assessment of the cavity stream capacity values demonstrates that the dissemination quality increments with cavity size since as talked about before, the cavity stream capacity values are relative to (V1b/2).

However, expanded cavity sizes have not ensured improved values of pressure drop across the seal. Despite the fact that LS3 and LS4 have almost similar values of Kv,

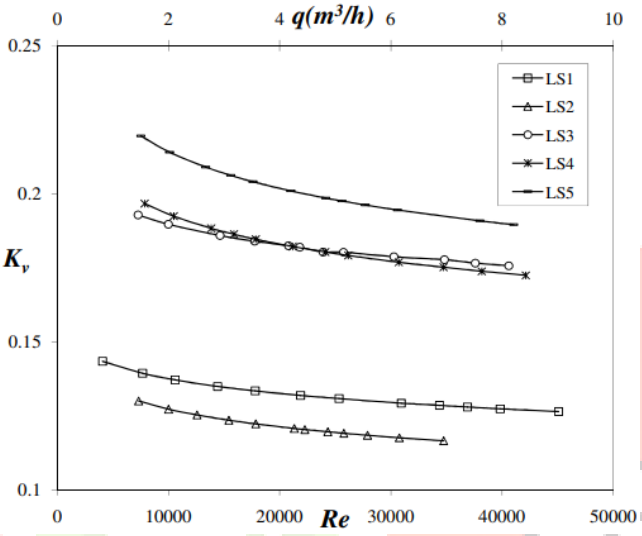

Figure 3: Variation of vortex loss coefficient $K_v$with *Re* and *q*

Figure 3 Variation of vortex loss coefficient Kv with Re and q for five CSLS execution of LS3 is better. Indeed, the values of Pr are the least for LS5 having the greatest cavity size of b = 5 mm and most elevated values of Kv. Higher pressure drop in a solitary cavity doesn't suggest bigger generally speaking pressure drop across the seal since the quantity of cavities per unit length additionally assumes a significant job. Henceforth, it is again observed that the pressure drop happening over a given length of labyrinth seal is a mind boggling capacity of the geometrical and flow variables.

With respect to the circular-grooved triangular cavity labyrinth seal the way that distribution close to the base zenith portions of a triangular cavity is extremely feeble. These backings the substitution of virtual cavity velocity term utilized in the hypothetical modeling of CSLS with another term called cavity loss coefficient Kc, to suit flow through triangular cavities.

$$\Delta p = \frac{\rho f Z a V^{2}}{4c} + K_c Z \rho V^{2} \qquad (12)$$

The first and second terms in Eqn. are synonymous with the comparing pressure drops in the annular and cavity portions of the triangular seal individually.

3.3 Need and Suitability of ANN Modeling

The labyrinth seal pressure drop is seen as dependent on various parameters in a muddled nonlinear manner. No absolutely logical methods for expectation is accessible. Albeit a decent measure of exploratory information has been produced for CSLS, the dissipating of values is considerable and sorting out them reasonably is an extreme assignment since various stages on the information parameters exist. Statistical methods having straight relapse would just have constrained expectation capacity. These considerations especially support the modeling of labyrinth seal pressure drop characteristics through ANN method which is perfect under the accompanying circumstances which exist in the present investigation as well:

- An enormous measure of input/output information is accessible; however, we don't know how to relate it to the ideal yield.
- The issue seems to have overpowering unpredictability, yet there is plainly a solution.

Additionally, in ANN modeling it is generally simple to fuse countless framework inputs. In addition, nonlinearities are managed in an inbuilt way during the preparation of the network with involvement/information and ANN can work outside the preparation domain viz. extrapolation. Generally, ANN applications are quickly developing in a wide assortment of fields. Marko et al. had utilized ANN for modeling a fluid dynamics issue. Rajkumar et al. applied ANN method for the streamlining of rocket motor components and demonstrated that with ANN approach, it is simpler to consolidate all the improvement inputs. In perspective on the above considerations, the current piece of the exploration work utilizes ANN as an improvement apparatus to rapidly recognize better CSLS configurations. No such past work managing the streamlining of labyrinth seals utilizing ANN is referred to in writing. The accompanying section gives a diagram of the procedures of ANN.

4. DATA ANALYSIS AND RESULT

4.1 ANN based optimization of CSLS and CFD analysis of optimal CSLS

Obviously, labyrinth seal pressure drop relies upon seal geometry and dimensions in a mind-boggling way. The LS3 and CTLS geometries however having the most elevated Pr value among the tentatively tried CSLS and CTLS individually, need not be a definitive ideal seal. It will bear some significance with assess in a deliberate manner, the arrangement of dimensions which relate to the ideal CSLS managed in this section and ideal CTLS in the following. In contrast to a hereditary calculation, the ANN model and the CFD methodology followed in this work come up short on the capacity of looking for the ideal dimensions in the solution field. Subsequently this ANN based streamlining method would decide the best seal from among a lot of elective seal structures.

Table 1 demonstrates the configurations of 55 applicant CSLS considered for the streamlining study, comprehensive of the five previously tried CSLS. The Pr values of the staying 50 achievable moderate estimated seals must be known with the end goal of examination. Creation and exploratory testing of these seals would devour a great deal of time and immense costs. Despite the fact that CFD analysis can be depended on, huge measure of CPU time would be required. As a result of the coupled nature of the governing equations, high number of geometrical variables, intricately interrelated turbulence parameters and nonlinear nature of pressure drops, any conventional advancement method will be bulky to execute. Hence, the semi hypothetical semi test model in relationship with ANN is utilized in the present optimization study.

Table 1: Configurations of candidate CSLS, ANN predicted $K_v$and calculated $P_r$at rated leakage (a)

Seal Name	***a*** **mm**	***b*** **,*d*** **mm**	***Z***	**$K_v$predicted by ANN**	**P_r**
LS2	1	2	40	0.12544	1.35137
LS22	1.25	2	37	0.12467	1.38234
LS23	1.5	2	34	0.12647	1.43784
LS24	1.75	2	32	0.12826	1.49326
LS1	2	2	30	0.13602	1.20427
LS16	1	2.25	37	0.12790	1.37487
LS17	1.25	2.25	34	0.13166	1.44910
LS18	1.5	2.25	32	0.13576	1.52657
LS19	1.75	2.25	30	0.14390	1.23198
LS110	2	2.25	28	0.15049	1.30792
LS111	1	2.5	34	0.13896	1.48051
LS112	1.25	2.5	32	0.14063	1.53477
LS113	1.5	2.5	30	0.14880	1.23834
LS114	1.75	2.5	28	0.15864	1.33757
LS115	2	2.5	27	0.16451	1.40835
LS116	1	2.75	32	0.15149	1.60018
LS117	1.25	2.75	30	0.17106	1.36906

Table 2: Configurations of candidate CSLS, ANN predicted $K_v$and calculated $P_r$at rated leakage (b)

Seal Name	*a* mm	*b ,d* mm	*Z*	$K_v$predicted by ANN	P_r
LS118	1.5	2.75	28	0.18419	1.49186
LS119	1.75	2.75	27	0.18808	1.54846
LS120	2	2.75	25	0.19169	1.60306
LS3	1	3	30	0.18760	1.51078
LS322	1.25	3	28	0.18922	1.55157
LS323	1.5	3	27	0.18960	1.58313
LS324	1.75	3	25	0.19253	1.63367
LS325	2	3	24	0.19076	1.31939
LS326	1	3.25	28	0.19017	1.52990
LS327	1.25	3.25	27	0.18894	1.54948
LS328	1.5	3.25	25	0.19204	1.60128
LS329	1.75	3.25	24	0.19103	1.29801
LS330	2	3.25	23	0.18829	1.30469
LS331	1	3.5	27	0.18969	1.52633
LS332	1.25	3.5	25	0.19045	1.53198
LS333	1.5	3.5	24	0.19117	1.27585
LS334	1.75	3.5	23	0.18872	1.28426
LS335	2	3.5	22	0.18497	1.28492
LS336	1	3.75	25	0.19026	1.53057
LS337	1.25	3.75	24	0.19059	1.24941
LS338	1.5	3.75	23	0.18914	1.26377
LS339	1.75	3.75	22	0.18555	1.26539
LS340	2	3.75	21	0.18085	1.26040
LS4	1	4	24	0.18997	1.23763
LS442	1.25	4	23	0.18941	1.25724

LS443	1.5	4	22	0.18616	1.26063
LS444	1.75	4	21	0.18154	1.25576
LS445	2	4	20	0.17618	1.03869
LS446	1	4.25	23	0.18974	1.23624
LS447	1.25	4.25	22	0.18683	1.24168
LS448	1.5	4.25	21	0.18232	1.23747
LS449	1.75	4.25	20	0.17693	1.02330
LS450	1	4.5	22	0.18848	1.22865
LS451	1.25	4.5	21	0.18347	1.22142
LS452	1.5	4.5	20	0.17816	1.01032
LS453	1	4.75	21	0.18801	1.22581
LS454	1.25	4.75	20	0.18249	1.01293
LS5	1	5	20	0.21016	1.13926

The ANN instrument with a feed forward back propagation learning algorithm inserted in the MATLAB 6.5 software is utilized as the network model. In the wake of trialing with various combinations of layers and neurons, a three-layered network utilizing the Trainlm preparing choice appeared in Figure 4 is picked. Trainlm is network preparing function that updates weight and inclination values as per Lavenberg-Marquardt calculation. The input layer has five neurons comparing to a, b, d, Z and q. The shrouded layer with a Tansig transfer function has twenty neurons and the output layer with a Purelin transfer function contains the solitary output neuron relating to Kv with Purelin being a straight transfer function.

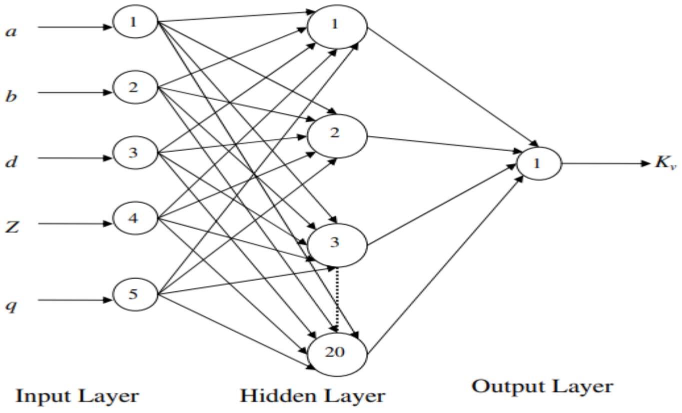

Figure 4: Architecture of ANN model used for CSLS

Actually, Pr is likewise straightforwardly attempted alongside Kv in the output layer utilizing 288 and 336 trial information got from the four geometries of LS1, LS2, LS3 and LS4 individually for a single target (Kv) and twin target (Kv and Pr) ANN models. In any case, the twin output model isn't exact enough. The underlying weights are picked indiscriminately and preparing is proceeded with various networks in an experimentation style. The weights are adjusted until an ANN model would foresee the objectives to an exactness level of inside 0.5 % of the exploratory outcomes for LS5. Networks not meeting the ideal correctness are disposed of.

The quantity of ages indicated is 20000 for a define execution objective of 10e-^{15}.

The CPU time required for the preparation is around 15 minutes in a similar PC that played out the previous revealed CFD investigations. The Kv values at the appraised leakage got from the simulation aftereffects of this ANN model for various up-and-comer seals. Utilizing these values of Kv on Eqn. the separate Pr values have been determined and recorded in this table.

It is seen that ANN has immediately recognized the up-and-comer seals LS116, LS120, LS324 and LS328 as the four potential ideal seal applicants. Their performances can be approved either by CFD analysis or test testing. CFD analysis is performed on these four seals. The rate over-forecast of Pr by ANN over CFD for these seals is seen as 1.3 %, 2.5 %, 4.2 % and 5.7 % separately. Since the base rate deviation of 1.3 % happened for the up-and-comer seal LS116, having a = 1 mm, b = 2.75 mm and Pr = 1.6; the equivalent is proclaimed as the ideal square cavity labyrinth seal.

The biggest deviations of 5.7% between the ANN and CFD predictions for the LS328 configuration can be ascribed to the way that both of its dimension's a and b are tentatively untested. This shows accessibility of extra preparing information from at any rate one tentatively tried seal having halfway values of a and b would have made the ANN predictions considerably increasingly exact for the untested seals.

Figure 5 demonstrates the variation of pivotal velocity along a radial line drawn through the center of a cavity of the ideal seal LS116 at the appraised leakage flow condition. The negative speeds are seen limited to a restricted locale close to the base of the cavity.

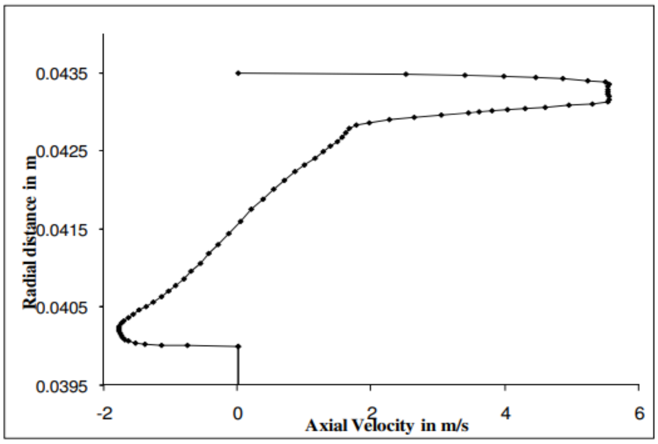

Figure 5: Variation of axial velocity with radial distance at the mid-plane of the cavity for the optimal CSLS viz. LS116

These figures demonstrate that the maximum values of axial velocity and turbulent kinetic energy happen in the free shear layer district at the top bit of the cavity. This likewise suggests the flow penetration into the cavity isn't obvious. Likewise, the maximum turbulent active energy value exists just in little pockets close to the stagnation district where the flow decelerates. Truth be told, the turbulence level in most center pieces of the seal is irrelevant. The lower distribution quality clarifies absence of turbulence beneath the shear layer.

The parameter K_v is seen as preferably appropriate for performing advancement contemplates in relationship with an ANN model. Further examinations concerning the vortex loss coefficient K_v can give indispensable insights to grow better labyrinth seal geometries.

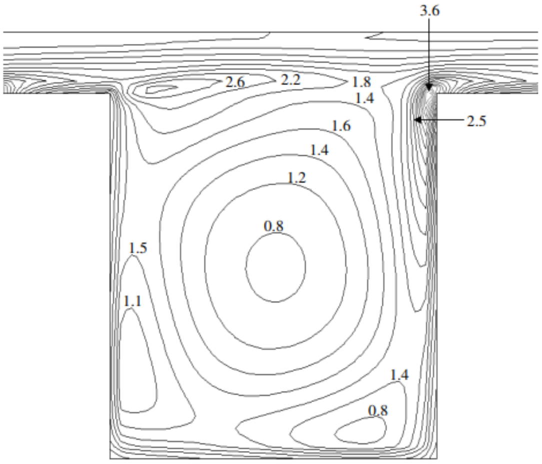

Figure 6: Contours of turbulent kinetic energy for the optimal CSLS-LS116

Without the ANN approach, broad trials/computational investigations would have been required to produce the values of Kv. It is conceivable that diverse applicant seals like LS116, LS120, LS324 and LS328 could strive for the ideal configuration status. Such a result of distinguishing more than one ideal seal configuration is helpfully conceivable just with the ANN based advancement scheme.

5. CONCLUSION

CFD analyses of the optimal seals confirmed the improvements caused by the cavity shape and captured performance parameter trends. The effects of turbulence levels in the (i) zones I of shear layer, (ii) downstream of the upstream tooth, and (iii) near the top of the cavity have been revealed by analysis of turbulence levels in the flow fields. The optimal CSLS vs. LS value is 116. Despite meeting only about 18.5 percent of the target value, the insights gained from these studies have paved the way for further research into newer types of labyrinth seals. With the help of the new terms used, such as virtual cavity velocity, vortex loss coefficient, and cavity loss coefficient, a semi theoretical-semi experimental model can be constructed. The model is simpler and has a single coefficient correlation. These coefficients gradually change in relation to the Reynolds number. It is simple and quick to identify the optimal circular-grooved square cavity and triangular cavity seals using the ANN technique and semi theoretical-semi experimental models. The P_r values of 1.6 are found in the best circular-grooved square and triangular cavity labyrinth seals.

REFERENCES

[1] Szymanski, A., Dykas, S., "Evaluation of Leakage through Labyrinth Seals with Analytical Models" TASK Quarterly: Scientific Bulletin of the Centre of Informatics-Tricity Academic Supercomputer & network, Vol.23, Issue1, (2019) 61~73.

[2] Guo, Y. & Zhang, Y. & Li, J.,"Numeric simulation of the internal flow in a complex trapeziform labyrinth screw pump", Vol. 23, (2008) 85~88

[3] Dereli. Y., Eser, Dursun., "Mathematical and Computational Applications, Vol. 9, Issue 3, (2004) 435~442.

[4] Eng, & Budea, Sanda & St, & Eng, Stefan & Simionescu, Stefan & Mircea, D & Cazacu.,"Experimental Research On Viscous Fluid Flow Through Sealing Labyrinths "Hidraulica" (No. 4/2014) Magazine of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics(2015).

[5] Naveen, S. N., “Numerical Study of Labyrinth Sela with Dimple Pattern Using Open Source CFD software” International Journal of Scientific & Engineering Research, Vol. 7, Issue 5, (2016) 280~ 284.

[6] Schettel, J., Deckner, M., Kwanka, K., Lu¨neburg, B., and Nordmann, R,. “Rotor-dynamic coefficients of labseals for turbines – comparing CFD results with experimental data on a comb–grooved labyrinth”, ASME Paper No. T2005-68732, (2005).

[7] Choi, D.C., and Rhode, D. L., “Development of a two–dimensional Computational Fluid Dynamics approach for computing three–dimensional honeycomb labyrinth leakage”, ASME Journal of Engineering for Gas Turbines and Power, Vol. 126 (2004) 794~802.

[8] Versteeg, H. K., and Malalasekera, W.,“An introduction to Computational Fluid Dynamics–the finite volume method”. Pearson Education Limited, England, second edition, (2007).

[9] Hirano, T., Guo, Z., and Kirk, R. G.,“Application of Computational Fluid Dynamics analysis for rotating machinery–part II: labyrinth seal analysis”, ASME Journal of Engineering for Gas Turbines and Power, Vol.127, (2005) 820~826.

[10] Budea, S., Simionescu, S., “HIDRAULICS” Vol. 1, (2014) 32~38.