RESEARCH ARTICLE OPEN ACCESS

Stress design approach of a screw conveyor for a specific flow rate

Nelson Javier Duarte Gutiérrez*, Rafael Alfonso Figueroa Díaz*, Pablo Alberto Limón Leyva*, Antonio de Jesús Balvantín García**, Pedro Cruz Alcantar***, Gabriel Rodríguez Echevarría****.
**(Electronic and Electrical Engineering department, Sonora Institute of Technology, Obregón, Sonora México.*
*** (Department of Mechanical Engineering, University of Guanajuato, Guanajuato, México.*
**** (Department of Mechanical Engineering, The Autonomous University of San Luis Potosí, San Luis Potosí, México.*
***** (Department of Infrastructure, Sales del Valle S.A. de C.V. company, Obregón, Sonora México.*

ABSTRACT
The screw conveyor is a compact, simple and low-maintenance system that is still used for conveying bulk material in our days. However, this simplicity in its components (screw, pipe and bearing supports) is compensated by its considerable complexity on the movement of the material along the helix in the screw. What causes, an easy reproduction of the equipment without considering some type of engineering analysis for these systems. This will commonly generate mechanical problems as a unexpected fracture in its components, changes in flow rate, shutdowns in production, higher energy consumption when there are oversized power systems, that the original system did not present. For this reason, this article proposes a design methodology to dimension the geometric characteristics of a screw conveyor system based on the necessary production capacity. Likewise, the procedure to be used to perform the mechanical analysis by resistance through the theory of distortion energy, and the strain generated in the pipe and screw components, that allow the system to work safely, is exposed.
***Keywords* –** Screw conveyor, flow rate, geometric characteristics, strain.

Date of Submission: 01-11-2021 Date of Acceptance: 15-11-2021

I. INTRODUCTION

Nowadays a wide need to transport bulk materials to different processing stages still be using by industries. For its simplicity one of the systems commonly used is the Archimedean screw. The screw conveyor is one of the old machines that continues in use, as presented [1], where a historical study of its use is presented, mainly for irrigation systems, as well as the approach to optimize the helix element is presented. considering water as a working fluid. While in [2] the Archimedean screw is used to generate electrical energy by coupling an electrical generator to the screw conveyor, focusing on the experimental part, and the effect of the inclination angle of the screw on the generation efficiency. However, the present study focuses on the transportation of bulk material, where the actually effort in the helix of the screw is greater than in the cases previously presented. For this, in [3] the analytical expressions are developed to determine the total power as a function of the slope angle, the friction forces in the supports and the required power to move the material to be transported, as well as the correction factors must be used. Continuing with his research, Aguilar in [4] uses the results of his previous work, applied to determine the axial force present in the screw to transport the bulk material. An experimental study for the determination of power is presented by [5] thus also, the influence that the size of the material has on the efficiency of the system, using sand as bulk material. Likewise, in [6] the study of the practical solution of the problem of jamming of two working screw conveyo´s in a coupled way is exposed, using polyamide plastic, as well as the redesign of the chain transmission system is shown. Likewise, in [7] the power required for an Archimedean screw applied to the recycling of polymeric material is studied, as a tool for pollution control in Nigeria. The semi-flexible coupling using different coupling screws is presented in [8] covering the parameters of transport capacity, bearings selection and the required power. The previous studies were presented mainly for horizontal systems or considering a maximum screw angle of 20 °. In [9] the study of a vertical screw conveyor is exposed that allows knowing its flow rate, the required power and the efficiency system, considering a gap between the external helix and the internal diameter of the pipe. Mathematical equations and their validation are presented experimentally through the use of a prototype. A screw conveyor at vertical position study is use to know the volumetric efficiency of a completely closed system as is presented in [10], proposing an analytical expression for the determination of the flow rate by means of the geometric parameters of the screw and pipe, as well as the vortex movement generated by the bulk material as it travels through the helix of the screw. While in [11], an experimental study is presented considering different parameters such as inclination angle, angular velocity and screw pitch, based on the analysis presented in [10]. Likewise, in [12] the analytical expressions obtained by Robert are used, specifically focusing on the influence of the radial clearance effect on the efficiency of the screw conveyor system, and by experimental data, its optimal distance is identified. However, the power analysis of the previously studies, assume a negligible feeding size. Yu et al in [13] present the analytical expressions for the calculation of power for horizontal transportation systems with extensive feeder, showing the validation of the equations developed through the use of scaled devices. While, in [14] the power calculated by Yu's methodology is experimentally evaluated for different kind if bulk materials, finding a good relationship between theoretical and experimental analysis. In the development presented by Yu, the perpendicular force applied to the helix of the screw is determined, this being used in [15] to carry out a study of fatigue of the screw conveyor.

Previous studies focus on the geometric parameters required to obtain the screw conveyor desing for specific flow rate, as well as its power. It is even used in finite element analysis to carry out fatigue studies on the helix of a screw conveyor. However, there is little information that allows the mechanical design to be carried out, to have a better control and understanding the stress concentration and deflection in the screw and pipe.

This research presents a stress design and strain analysis of screw conveyor systems to be used for small and medium-sized companies, which will allow to optimize the diameters of the hollow shaft and pipe, for specific speed. The mechanical design begun with the company requirements. This methodology takes into account the manufacturing processes used actually by the company, to carry out the mechanical design of the system.

I. SCREW CONVEYOR SYSTEM

The screw conveyor system allows the transfer of bulk material by two main components: screw and pipe. Like shown in the Figure 1.

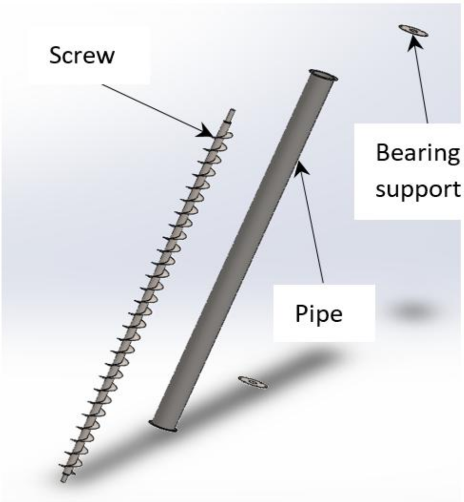

Figure. 1. Main components of an Archimedean screw.

One of the components shown in Figure 1 is the pipe, which is an element that does not have motion. While the screw contains a helix mounted on a hollow shaft on which the bulk slides and at the ends it is supported by bearings. One of the initial parameters for the study is the determination of the flow rate of the equipment.

1.1 Flow rate analysis in screw conveyor

To calculate the flow rate of the screw represents a fundamental parameter to develop the design of these systems. Calculating this parameter as presented in [6, 16] is given by the equation 1.

$$Q = 60\left(\frac{\pi}{4}\right)\left(D^2 - d^2\right)\delta n f \rho c\beta \quad (1)$$

Where Q , is the flow rate of screw conveyor $\left[\frac{kg}{hr}\right]$, D , external diameter of screw (helix) [m], d the external diameter of hollow shaft [m], δ is the screw pitch [m], n the screw angular velocity [rpm], f the coefficient of converyor´s filling (according to bulk material), ρ is the bulk density $\left[\frac{kg}{m^3}\right]$ and $c\beta$, incline factor.

A similar expression can be found in [8]. While different international manufacturers that design, build and maintain this kind of system, such as [17, 18] present the calculation of the flow rate using experimental data in tables, due to the lack of uniformity in the filling during the transport of the material. However, their methodology, even though it may help for make the selection of a commercial screw conveyor, does not allow us to know the geometric parameters required, as shown in equation 1.

While known factors depending on inclination ($c\beta$) are presented in [8] for different varying angles. Therefore, using a quadratic interpolation, the following mathematical expression is generated.

$$c\beta = 0.0003B^2 - 0.0237B + 1.0043 \quad (2)$$

where B is the inclination angle of the screw conveyor in degree. While in [16] an experimental method is presented for the evaluation of the inclination factor when the material is polypropylene.

The initial design requirements, provided by the regional company, are summarized below:

- Flow rate: $20\frac{ton}{hr}$.
- Screw angle: $60°$.
- Bulk material: Salt.
- Angular velocity of shaft: $200\,rpm$.
- Material: Food grade stainless steel.
- Screw and pipe must use a seamless pipe.
- Total lenght: $12\,m$.
- Eliminate the internar support in the screw.
- Eliminate the metal burr by the fricction of screw and pipe.

Therefore, equation 1 presents a good solution to obtain the necessary geometric parameters (D, d y δ) through the iteration process, until reaching a close solution to the required flow rate.

1.2 Power analysis in screw conveyor

Knowing the flow rate of the screw, it is necessary to determine the require mechanical power of the system. For this, the classical method commonly presented in the literature requires the calculation of the total power as: $P_{Total} = P_{mat} + P_{sc} + P_{inc}$, where P_{mat} is the power necessary for conveying material , P_{sc} is the driving power of conveyor at no load and P_{inc} is power requirement for inclination at the conveyor.

Likewise, the first component of the power is given by the following expression.

$$P_{mat} = \frac{Q_{ton} L\, CF}{367} \quad (3)$$

where P_{mat} is the power necessary for conveying material [Kw] , Q_{ton} is the flow rate in $\left[\frac{ton}{hr}\right]$, L the screw length (m) , CF is the progress resistance coefficient ($2.5 - 4$).

While the second component is shown below.

$$P_{sc} = \frac{DL}{20} \tag{4}$$

where P_{sc}, is the driving power of conveyor at no load $[Kw]$.

Finally, the third component is given by the following equation.

$$P_{inc} = \frac{Q_{ton} L sen(B)}{367} \tag{5}$$

where P_{inc} is power requirement for inclination at the conveyor $[Kw]$.

The power given by equations 3 to 5 the single feeder size are negligible. However, for particular cases where feeder is extensive, there are limitations. An alternative proposal to determine the power for a screw conveyor with extensive feeder is presented in [13].

1.3 Reaction force and strain in screw conveyor system

From a mechanical design point of view, the study system requires an analysis of the stress along of the hollow shaft of the screw and trough, as well as the deformation generated between them. Therefore, the analytical expressions in order to find the reaction forces and stress presented in the screw and pipe are presented. A general free-body diagram for force analysis is presented in the following figure.

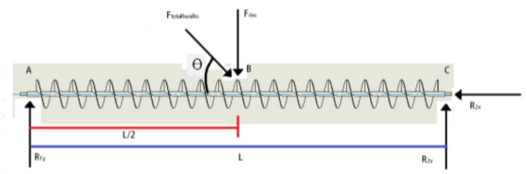

Figure 2. Screw free-body diagram.

Considering that $F_{totalhusillo} = F_{Whusillo} + F_{Wsal}$ where, $F_{Whusillo}$ is the force exerted by the screw´s own weight, F_{Wsal} is the weight of the salt and the angle of inclination of the screw is $\theta = B$. In addition F_{des} is the unbalance force of the screw. To determine the unbalance force, the residual unbalance concept presented in [19] is used through the following expression.

$$F_{des} = U_{res} n^2 \tag{6}$$

where U_{res} is the residual unbalance.

However, the forces present in the pipe are different from those considered for the screw, and we have the expression as shown below.

$$F_{totalArtesa} = F_{Whusillo} + F_{Wsal} + F_{WArtesa} \tag{7}$$

It should be considered that the pipe will not have the effect of the unbalance force because it does not have angular motion.

From Figure 2, and applying the procedure presented in [20], the reaction forces in the supports are obtained, such as.

$$R_{1y} = F_{des} + (F_{totalhusillo}\, sen\,\theta) - R_{2y} \tag{8}$$

$$R_{2y} = \frac{1}{2}(F_{des} + F_{totalhusillo}\, sen\,\theta) \tag{9}$$

For analysis of this article, the horizontal component (R_{2x}) that would help in the selection of the bearing to be used is not required.

Once the reaction forces have been determined, the moment equations are developed to calculate the stress along the entire hollow shaft. The deduction of the moment expressions is carried out considering the following figure.

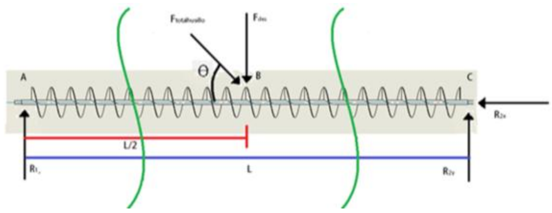

Figure 3. Segment distribution for moment analysis in screw conveyor.

In the previous figure the sections $A-B$ and $B-C$ are shown, where the corresponding moment expressions are shown in the following equations.

$$M_{AB} = R_{1y}x \qquad (10)$$

And

$$M_{BC} = x\left(R_{1y} - F_{totalhusillo}\,sen\theta - F_{des}\right) + \left(F_{totalhusillo}\,sen\theta\left(\frac{L}{2}\right) + F_{des}\left(\frac{L}{2}\right)\right) \qquad (11)$$

where x is the temporal distance taking as the starting point of the reaction R_{1y}. Considering the following reduction for the deflection analysis, we have that $A_{aux} = R_{1y} - F_{totalhusillo}\,sen\theta - F_{des}$, and $B_{Aux} = F_{totalhusillo}\,sen\theta\left(\frac{L}{2}\right) + F_{des}\left(\frac{L}{2}\right)$. Likewise, the boundary conditions to be used are shown in the following figure.

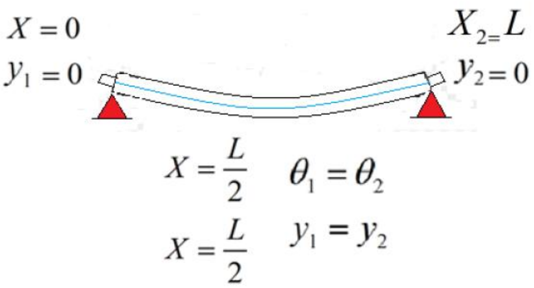

Figure 4. Boundary conditions.

Therefore, using the elastic curve method presented in [20, 21] for the section $A-B$ of figure 4, the deformation section is given by the equation 12.

$$y_{A-B} = \frac{1}{EI}\left[\frac{1}{6}R_{1y}x^3 + C_1x\right] \qquad (12)$$

where y_{A-B} is strain in the first section $A-B$, E is the modulus of elasticity, I is moment of inertia of cross section.

$$y_{B-C} = \frac{1}{EI}\left[\frac{1}{6}A_{aux}x^3 + \frac{1}{2}B_{aux}x^2 + C_3x + C_4\right] \qquad (13)$$

where y_{B-C}, is strain in the second section.

While the constants of integration of equations 12 and 13 are as follows.

$$\begin{bmatrix} C_1 \\ C_3 \\ C_4 \end{bmatrix} = \begin{bmatrix} 0 & L & 1 \\ 1 & -1 & 0 \\ \frac{L}{2} & -\frac{L}{2} & -1 \end{bmatrix}^{-1} \begin{bmatrix} -\frac{1}{6}A_{aux}L^3 - \frac{1}{2}B_{aux}L^2 \\ \frac{A_{aux}L^2}{8} + \frac{B_{aux}L}{2} - \frac{R_{1y}L^2}{8} \\ -\frac{R_{1y}L^3}{48} + \frac{A_{aux}L^3}{48} + \frac{B_{aux}L^2}{8} \end{bmatrix} \qquad (14)$$

Equations 8, 9, 10, 11, 12 and 13 are used for the analysis of the hollow shaft and the pipe for the strain study.

1.4 Stress analysis

Unidirectional stress analysis is performed using von Mises theory, as presented in [22, 23] and is expressed considering a hollow shaft as follows.

$$\sigma = \sqrt{\left(\frac{32Md}{\pi\left(d^4 - d_{in}^4\right)}\right)^2 + 3\left(\frac{16Td}{\pi\left(d^4 - d_{in}^4\right)}\right)^2} \qquad (15)$$

where σ is the stress using the distortion energy theory, d_{in} is the inner diameter of the shaft, T is the torque on the screw, and M is the bending moment.

The equation 15 allows to know the stress distribution along the screw and pipe. For this analysis, the diameter uniformity in the hollow shaft of the screw and pipe is considered. As a practical matter, however, a solid shaft section is used at the ends of the screw to allow the bearings be attached.

Finally, the factor of safety along the screw must be determined and is obtained using the following expression.

$F.S. = \frac{S_y}{\sigma}$	(16)

where $F.S.$, is the factor of safety and S_y, is the tensile strength yield.

II. RESULTS

During the study carried out, taking as a basis the requirements requested in the equipment, it was found that, for a desired length of 12 m, without having any internal support, as well as the requested working speed, it was not possible to satisfy these parameters of simultaneously. Therefore, it is proposed to divide the length at the half at $L = 6\,m$. Another limitation presented is the space limitations, where the installation of the equipment would be carried out. Therefore, by using equation 1, we have the following geometric parameters that the screw must have.

Table 1.- Geometric parameters with flow rate at 20 ton/hr.

Parameters	Unit
Screw length (L)	$6\,m$
Helix outer diameter (d)	$0.286\,m$
Shaft inner diameter (d_{in})	$0.102\,m$
Helix Pitch (δ)	$0.216\,m$
Angular velocity of shaft (n)	$200\,rpm$
Inclination angle ($c\beta$)	$60°$
Coefficient of converyor´s filling (f)	0.25 (dimensionless)
Bulk density (ρ)	$848.97 \left[\frac{kg}{m^3}\right]$
progress resistance coefficient (CF)	4 (dimensionless)
Screw material (commercial)	$316L$ stainless steel

The last geometrical parameters get a flow rate of $20.4\frac{ton}{hr}$, complying with the requested company requirements. From the parameters in table 1, and the sum of equations 3-5 we have that the total power is $P_{Total} = 2.5\,hp$. However, this is considering direct coupling, with ideal conditions and with $F.S.=1$. For the selection of the actuator to be used, the efficiency of the transmission system to be used must be considered. In [18] a table of efficiencies in commercial power transmission systems is presented and can be show that is in the range of $0.87 - 0.95$. Likewise, it is recommended to use a safety factor in the range of $2 - 3$ for the theoretical power.

Then the calculation of the reaction forces is carried out, so the total force of the screw must be find and that has a magnitude of $F_{totalhusillo} = 3.82\,E3\,N$ with inclination angle at $\theta = 60°$. While the force due to residual unbalance is $F_{des} = 56.69\,N$ at the screw angular velocity of $n = 200\,rpm$, considering a quality grade for agricultural machinery based on the ISO 1940-1 standard.

Therefore, it is found that the reaction forces at the ends of the screw by means of equations 8 and 9, is of $R_{1y} = R_{2y} = 1.73\,E3\,N$.

This generates from equations 10, 11 and 15 the stress distribution along the screw, as shown in the Figure 5.

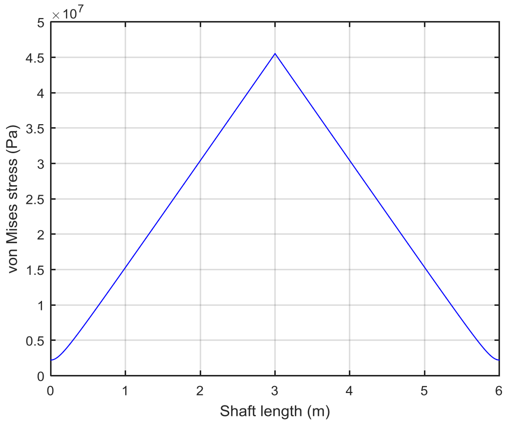

Figure 5. Stress distribution along the screw.

Figure 5 shows that the maximum stress concentration occurs at a length of with a magnitude of $\sigma = 45.5\,MPa$. Generating from equation 16, a graph of the factor of safety as shown below.

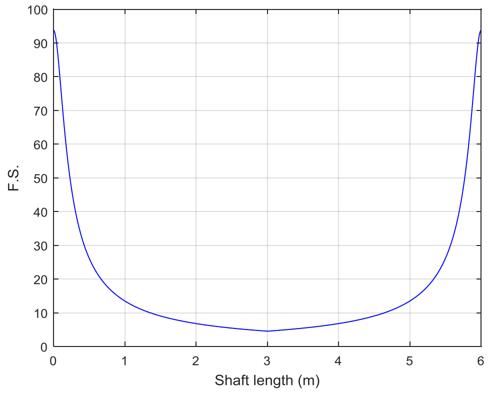

Figure 6. Safety factor distribution diagram along the screw.

From Figure 6 there is a minimum safety factor of $F.S. = 4.5$. This indicates that the screw will work rigthly for the applied load.

Another parameter of analysis is to know the maximum deformation of the screw and its location. So the moment equations obtained will be used, as well as equations 12 and 13. What generates a strain pattern as shown in Figure 7.

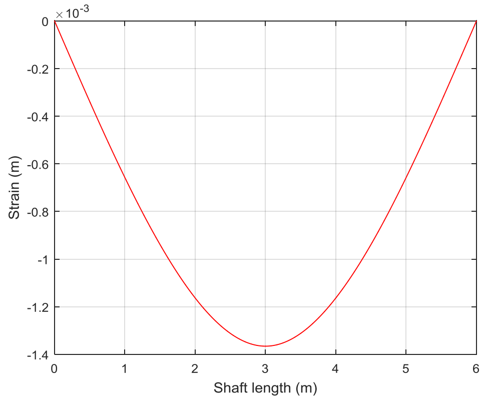

Figure 7. Strain distribution along the screw.

The previous figure shows the maximum deflection appearing at $L = 3\,m$ with maximum value of $1.13E-3\,m$.

It should be considered that the diameters used in Table 1 are commercially available in the region, as well as that they do not contain seams. From the analysis shown for the screw, based on Figures 5 and 6 it is concluded that the system will work safely to transport salt with a flow rate of $20\,\frac{ton}{hr}$ at the screw angular velocity of $200\,rpm$.

A second part of the study focuses on the analysis of the pipe of the conveyor system. The general parameters are shown in the following table.

Table 2.- Geometric parameters of the pipe for flow rate at 20 ton/hr.

Parameters	Unit
Screw outer diameter (D)	$0.286\,m$
External diameter of the pipe (d_{Ar})	$0.324\,m$
Inner diameter of the pipe ($d_{in\,Ar}$)	$0.305\,m$
Screw material (commercial)	$316L$ stainless steel

Radial clearance (c)	$9.5\,mm$
Average grain size	$0.3\,mm$

An analysis similar to that performed on the screw was carried out on the pipe to determine its resistance and its maximum deflection presented. Where a maximum safety factor is determined, which allows to work without problems for the specific flow rate.

The maximum strain in the pipe, becomes a fundamental parameter to find and avoid friction between the screw and pipe and is known using Table 2 and equations 12-13. The strain along the pipe is shown in Figure 8.

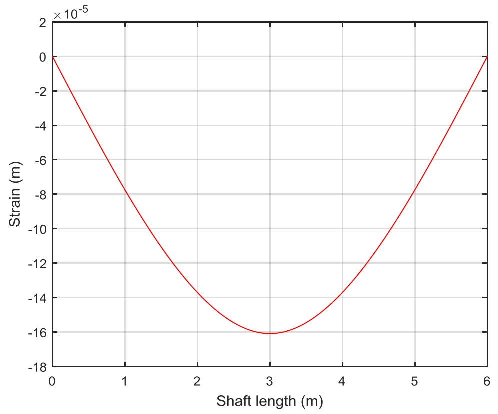

Figure 8. Strain distribution along the pipe.

In Figure 8, the maximum strain in the pipe is $0.16\,mm$ and is at $L = 3\,m$. In [5] it is recommended that the radial clearance should not be greater than three times the maximum size of the particle to be transported, so as not to affect the transportation efficiency of the system, being a maximum recommended radial clearance size of $0.9\,mm$. However, due to the actual manufacturing tolerance in the company they used a radial clearance of $c = {}^{3}\!/_{8}\,in = 9.5\,mm$.

From the maximum strain of the screw and pipe, presented in Figures 7 and 8, it is observed that there will be no friction inside the pipe wall, however, the efficiency of the system has to be determined experimentally, due considerable radial clear used.

III. Conclusion

The Archimedean screw is a mechanical system used for the transportation of bulk material, as well as in irrigation or sludge drainage systems. Considering that the best mechanical design is the one that has the least number of moving parts and that can be built with the materials and machines found at local area, then the screw conveyor would be the best option for the transportation of bulk material. For grain producing areas, this system is widely used to transport material between different points of the production process, and it also represents an economical way of doing it. However, due to the "simplicity" in its components, it is common for these systems to be built empirically, as well as the manufacture of their parts. This generates that, when reproducing the geometric specifications and power system, without taking into account parameters such as the angle of inclination, the radial clearance, the material, among others, appear new are mechanical problems that in the original system did not have. Therefore, based on the specific need of a local company, the stress mechanical design and strain of an screw conveyor is presented for a flow rate of $20\,\frac{ton}{hr}$ of salt at a specific angular velocity of $200\,rpm$. Due to the impossibility of complying with the total length initially requested ($L = 12\,m$), and the need not to have supports inside the pipe, to avoid the presence of friction between the outer helix of the screw and the inside of the pipe, it was decided to design two conveyor systems with a length of $L = 6\,m$, for which the expressions used allow us to determine the geometric parameters necessary to meet the initial requirement of flow rate, and that was approved by the company. Due to the need to eliminate internal supports that allows controlling the longitudinal strain in the screw, only the supports at the ends are considered, so the analytical expressions are presented to know the reaction forces present, as well as the analysis methodology of stress using the distortion energy theory for the screw and pipe elements.

Likewise, the analysis carried out to know the strain generated for the stress present in the two main components is exposed. This study to avoid the contact between the mechanical parts when they are in operation. However, the screw angular speed is a parameter to be taken into account during the operation of the equipment, because the initial unbalance force is a function of the square of the angular speed, therefore, an increase in speed generate an strain increase to take into account seriously. Finally, the methodology presented will allow the redesign of different screw conveyor, as well as the power system, that are currently used in the production line of the company that requested the study.

Acknowledgements

Technological Institute of Sonora supported this work by the project PROFAPI-2021.

.REFERENCES

[1]. Rorres C. The turn of the screw: optimal design of an Archimedes screw. *Journal of Hydraulic Engineering*, 126(1), 2000, 72-80, ISSN 0733-9429.

[2]. Siswantara A. I., Warjito, Budiarso, Harmadi, Gumelar M., Adanta D. Investigation of the α angle's effect on the performance of an Archimedes turbine, *5th International Conf on Power and Energy Systems Engineering*, 2018, 19-21 September 2018, Nagoya, Japan.

[3]. Aguilar P. F., Consideraciones en el cálculo de potencia de un transportador de sin fin, *Revista de Ingeniería y Transport*, 15(2), 1994, ISSN: 0258-6029.

[4]. Aguilar P. F., Análisis de la fuerza axial en un transportador de sinfín, *Revista de Ingeniería Mecánica*, 2(1), 1999. ISSN: 1029-516X.

[5]. Uematu T., Nakamura S., A study of a screw conveyor. *Bulletin of The Japan Society of Mechanical Engineers*, 3(12), 1986, https://doi.org/10.1299/jsme1958.3.449.

[6]. Goytisolo R., Noa A., Fernández C., Análisis y solución de avería del acoplamiento del sinfín de fondo de la bañera de una planta de plástico mixto, *Revista Ingeniería Mecánica*,. 2004, 3(1), 79-85. E-ISSN: 1815-5944.

[7]. Ikechukwu G. A., Ekwuozor S. C., Chinedu O. K., Design and characterization of a model polythene recycling machine for economic development and pollution control in Nigeria, *Proceedings of the World Congress on Engineering*, July 3-5, 2013, ISSN: 2078-0958.

[8]. Santanu C., Anshuman M. Produc design of semi flexible screw conveyor, *Journal of Mechanical and Civil Engineering*, 11(5), 2014, 01-13, ISSN: 2320-334X.

[9]. Rademacher F. J., Some aspect of the characteristics of vertical screw conveyors for granular material, *Powder Technology*, 9(2), 1974, https://doi.org/10.1016/0032-5910(74)85011-4.

[10]. Roberts A. W., The influence of granular vortex motion on the volumetric performance of enclosed screw conveyors, *Powder Technology*, Elsevier; 104(1), 1999, https://doi.org/10.1016/S0032-5910(99)00039-X.

[11]. Li M., Luo J., Wu B., Hua J. Experimental research of the mechanism and particle flow in screw conveyer, 36(1), 2018, https://doi.org/10.18280/ijht.360123.

[12]. Luu T. T., Study on the radial clearance of the screw conveyor for transporting cement, *Science & Technology Development Journal-Engineering and Technology*, 2(3), 2019, https://doi.org/10.32508/stdjet.v2i3.577.

[13]. Yu Y., Arnold P. C., Theoretical modelling of torque requirements for single screw feeders, *Powder Technology*, 93(2), 1997, https://doi.org/10.1016/S0032-5910(97)03265-8.

[14]. Dai J., Grace J. R., A model for biomass screw feeding, *Powder Technology*, Elsevier, 186(1), 2008, https://doi.org/10.1016/j.powtec.2007.10.032.

[15]. Fu Y. F., Gong J., Li W. P., Yang Z. M., Fatigue life assessment of screw blades in screw sand washing machine under extreme load, *American Journal of Mechanical Engineering*, 5(1), 2017, doi: 10.12691/ajme-5-1-1.

[16]. Bolat B., Bogoclu M., Increasing of screw conveyor capacity, *Journal of Trends in the Development of Machinery and Associated Technology*, 16(1), 2012, ISSN 2303-4009.

[17]. FMC Technologies, Link-Belt screw conveyors. 2013, Houston, Texas USA.

[18]. Martins Screw Conveyor Components and Accessories, Sec Ha. 2006, https://www.martinsprocket.com/mobile/Products/ScrewConveyor.aspx.

[19]. ISO 1940-1, Mechanical vibration-balance quality requirements for rotors in a constant (rigid) state – Part. 1: Specification and verification of balance tolerances, 2003.

[20]. Beer F. P., Johnston E. R. DeWolft J. T., *Mecánica de materiales* (Mc Graw Hill, 2010).

[21]. Pytel A., Singer F., R*esistencia de materiales: Introducción a la mecánica de sólidos* (Harla, 1994).

[22]. Budynas R., Nisbett J., *Diseño en ingeniería mecánica de Shigley* (Mc Graw Hill, 2008).

[23]. Norton R. L., *Diseño de máquinas un enfoque integrado* (PEARSON, 2011).