Preliminary Design of a Non-Destructive IV Tube Measurement

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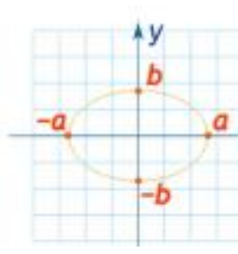
Abstract

Different types of non-destructive testing (NDT) were researched and explored: optical measuring, ultrasonic testing, radiographic testing, and liquid penetrant testing. The purpose of this research is to explore a preliminary design a non-destructive IV tube measurement method based on research of different types of non-destructive testing (NDT). At least one NDT method would be implemented into the design, after considering which design would be most suitable. It was chosen that a system of two different NDT methods would be chosen: optical measuring and radiographic testing. Optical measuring would be used to measure the outer diameter, ovality, and eccentricity while radiographic testing would be used to measure the inner diameter accurately.

Introduction

For the Capstone Project, the new purpose is to explore a preliminary design a non-destructive IV tube measurement method based on research of different types of non-destructive testing (NDT). Different types of non-destructive testing (NDT) were researched and explored: optical measuring, ultrasonic testing, radiographic testing, and liquid penetrant testing. The NDT method is used to test material discontinuities without causing any damage or defects to a product that is being evaluated [1, 3].At least one NDT method would be implemented into the design, after considering which design would be most suitable. In addition, it will use optical measurements in order to measure the following parameters of the IV tube: inner diameter, outer diameter, ovality, and eccentricity. Ovality describes how far off are the measurements when measuring various segments of a circular object. The difference of minimum and maximum diameters and the nominal diameter of a tube are calculated as a ratio, as shown below and converted to a percentage. Ideally, the percentage of ovality should be low; a general guideline is around 5% [17]. Eccentricity is a measurement that determines how circular a circle is; the eccentricity equation of an ellipse is used and shown to the right.

$$\text{Ovality }\% = \frac{(\text{Max OD - Min OD})}{\text{Nominal OD}} \times 100$$



$$\frac{\sqrt{a^2 - b^2}}{a}$$

Equations for ovality and eccentricity [17,18]

Analysis of Methods and Overview of Proposed Preliminary Design

Though many partial solutions to the quality control of small, thin-walled, plastic IV tubing exist, there is no one solution, currently available, that covers the ovality, eccentricity, inside and outside diameter testing. Instead, we would recommend the implementation of multiple testing systems working in tandem with each other to give the desired testing capability. For inner diameter, an x-ray based quality control system could be implemented that would accurately measure the quality of the product being produced for defects in wall thickness. For ovality, eccentricity, and inner diameter of the IV tube, a three-axis optical quality control system would detect any ovality in the IV tubing with a small margin of error. Using these methods in conjunction with each other would satisfy the requirements of the project.

The negatives associated with this selection include the cost of running multiple quality control methods simultaneously. Based on our research, however, it would be the only way to effectively cover the required quality control aspects with any accuracy at all. The speed of testing would also be a consideration. Optical measurement systems can measure outside diameter and ovality instantaneously however to measure the inside diameter of the wall with any accuracy the use of x-ray testing is required and as such will slow down the testing time. This downtime can be reduced by selectively testing with the x-ray setup while using the optical testing at all times during production.

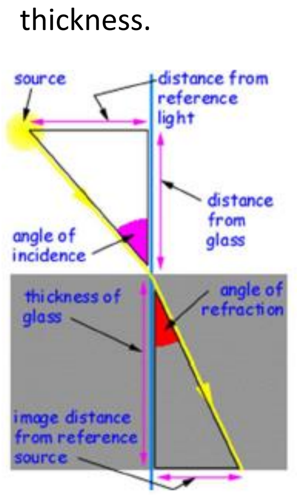
Proposed Preliminary Design of IV Tube Measurement System

How it Measures the Parameters of the IV Tubing: Optical Measuring

The proposed design will use two different types of non-destructive testing: optical measuring and radiographic testing or x-ray testing. Optical measuring will be used to measure the ovality, eccentricity, and outer diameter of the IV tube. One of the equations relating to optical measurements is called the refractive index, which is indicated as: $N = c/v$

Where c represents the speed of light within a vacuum and v represents the phase velocity. The refractive index of a material or other medium is a dimensionless value that describes how fast light travels through it. When light hits a surface of a material, it is usually refracted or bended. This is explained through Snell's Law. The angles of the incident and refractive rays of light are normal to a surface of the medium at the refraction point. Snell's law is dependent on the type of medium that light rays are traveling to [11].

To find the refractive index of a medium, trigonometric principles are used. The following figure shows how the incident and refraction rays form two right triangles relative to the light source [12]. First the total distance that the light rays travel from the referenced light source is determined. Next the sines of angles are used to calculate the angles of incidence and the angle of refraction. Finally, the ratio of the sine of the angle of incidence and the sine of the angle of refraction is evaluated to find the refractive index [12]. In order to determine the thickness of a material or medium, two useful parameters are the distance of the refraction ray and the distance of the referenced light source. Trigonometry is then used to find the thickness.



Schematic showing the trigonometric relations between incidence and refraction rays and their angles [12]

Material	Refractive Index
PVC (polyvinyl chloride)	1.531
Polyethylene	1.476
Polypropylene plastic	1.49
Nylon	1.525

The table above shows refractive indices of different materials that are used to create and manufacture IV tubes [10].

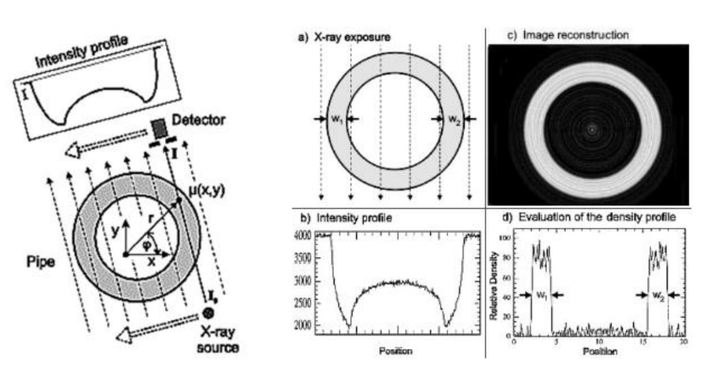
Ideally, multiple axes beams should be used for measurements to be as accurate as possible. It was decided that a three-axis optical quality control system should be used not only to measure the outer diameter but also the ovality and eccentricity of the IV tubes. This type of three-axis optical quality system will use laser micrometers as the light source. The lasers are coplanar and spaced out at 60^0. When it measures the outer diameter of the tube, it will be scanned in three directions by the laser micrometer. These lasers will record the measurements and afterwards the average of the measurements will be calculated [16]. To measure the ovality and eccentricity of the IV tubes, the measurement system will utilize the triple axis lasers to measure various parts or segments of the tube's curvature, similarly to how it would measure the outside diameter. The system would take in the measurements to find how much of an oval and eccentric the tube is.

How it Measures the Parameters of the IV Tubing: Radiographic Testing

Radiographic testing is the second measurement system in this preliminary design that would measure the inner diameter of the IV tubes. Specifically, x-rays are used as the basis for measuring. One specific method to measure the tube's inner diameter is called computed radiography. In any radiographic testing, the occurrence of attenuation is present. This is when x-ray beams experience a reduction in its intensity when it travels through matter [12]. Some causes of the reduction in intensity include the absorption or deflection of photons. An attenuation coefficient is dependent on the material where x-rays travel to, and it describes the quantity of radiation that is attenuated by a given thickness [12]. In small values of a material's thickness, the equation for the linear attenuation coefficient is used according to the following relation: $\mu = \frac{\Delta N}{N \Delta x}$ where N represents the number of photons that is removed from the x-ray beams and Δx represents the material's thickness. This is only valid for small thickness values since the attenuation coefficient is not linear with large thickness values [12]. In addition, the following two equations are used to calculate the attenuation at any thickness when the values of the photon number (1) or incident and transmitted photon intensity (2) are measured:

(1) $I = I_o e^{-\mu x}$ (2) $N = N_o e^{-\mu x}$

where I is the x-ray beam intensity through an absorber at the material's thickness at x, I_0 is the beam intensity through an absorber at the material's thickness at 0, N is the number of transmitted photons, and N_0 is the number of incident photons [12]. The following diagram in the bottom left shows a general setup to perform a measurement using this type of imaging [13].



Schematic of the setup of a typical radiographic testing of a tube [13]

In this setup, the radiation source is pointed towards the object. In order for the x-ray beams to not spread as it travels, a collimator is used. The x-ray beam travels in a continuous matter through the pipe, then a detector records the transmitted radiation and stores it as an intensity profile. The detector is rotated at an angle around the object at each x-ray crossing. When the scanning is completed, the profiles are processed and reconstructed using computer software [13]. This process measures the thickness of a tube with a wall thickness. For the IV tube measurements, the value of the wall thickness can be used to calculate the inner diameter, when the outer diameter of the tube is known.

Conclusion and Further Considerations

The purpose of this project is to explore a preliminary design a non-destructive IV tube measurement method based on research of different types of non-destructive testing (NDT). It was chosen that a system of two different NDT methods would be chosen: optical measuring and radiographic testing. Optical measuring would be used to measure the outer diameter, ovality, and eccentricity while radiographic testing would be used to measure the inner diameter accurately.

Further work that can be done include the following. One is to create a 3D model of the measurement system through utilizing a CAD program such as Solidworks. Another aspect can be to research costs of the two measurement systems and comparing different market values. In addition, research of different measuring software can be researched and how they are programmed to record measurements.

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