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(54) Title: MAXIWHEEL™ - MACHINERY FOR AUTOMATIC X-RAY INSPECTION OF WHEELS

(57) Abstract: The lightweight manipulator has a minimum number of moving parts for maximum efficiency. It’s very robust, simple to produce and maintain. The manipulator consists of a tilt table and a “C” arm with variable geometry in regards to table for x-ray tube and/or imaging system. The manipulator has 6 AC servo axes of movement: 2 tilt axes (table and C-arm), 2 wheel rotation axes (if one fails), vertical axis (magnification) and horizontal axis (C-arm with x-ray tube incl. shutter and filter) and image intensifier (9" or 12"). The tilt table and the “C” arm tilted by shaft mounted drives. The wheel is, driven by two pairs of gear wheels (two inclined gear boxes in V-shape). The optimum gripping geometry for small and big diameter wheels is possible using V-shape gear-boxes arrangement. The wheel is gripped on lower rim flange (Fig. 8) instead of upper rim flange (Fig. 9). No belts or chains to adjust and lubricate. The manipulator has a very small footprint (1500mm x 1500mm). The wheel transfer in and out is by gravity and as short as possible. No chain to adjust or belt to slip, and no drive. The two swing out bumpers absorbs the kinetic energy of the wheel, the bumpers swing out, and the wheel slips in on a sloped frame to guide the wheel rim into the fixed drive wheel and an air cylinder operated frame lifts the back of the wheel into position to close the gripper arms, retract the lift frame, swing out the bumpers and rotate the wheel for inspection. In order to position the wheel into the right orientation, the table and the “C” arm can be
PATENT APPLICATION OF
FRANCIS HORVATH AND ASHLEY STONE

FOR

MAXIwheel™ - Machinery for Automatic X-ray Inspection of Wheels

BACKGROUND

Field of the Invention

This invention relates to fully automated x-ray inspection systems for the non-destructive inspection of light alloy wheels. That means inspecting and locating anomalies (defects) in automobile light alloy wheels by x-ray image analysis.

Description of the Prior Art

The use of X-rays for non-destructive inspection of manufactured objects is well known. Because of their ability to penetrate a manufactured object, x-ray inspection has the ability of revealing internal flaws and defects in the object. Therefore related apparatus and methods are often used in the inspection of welded joints and cast or forged metal objects.

The wheel gripper (see Fig. 1) had some problems that would not have been evident during design, but were clearly visible once the machine was in operation. The wheel gripper gears were shaft driven, with the shaft exposed. This caused the shaft to become dirty and jammed.

The gripper was redesigned to use a chain drive (Fig. 2) for the wheel instead of the older shaft drive. Unfortunately, this caused problems for maintenance, as the chains would stretch, sag, become clogged with aluminum debris, and required frequent lubrication.
The wheel gripper (Fig. 3) contains four driven rollers of which two can be opened pneumatically be which are holding the beauty-face wheel flange. The rotation drive acts upon four guide rollers, two of them stationary and two of them with a pneumatic opening mechanism. All four are driven jointly and synchronously. The two swiveling guide rollers automatically adjust to the diameter of the wheel, thus enabling a form-locked and force-locked guidance of the wheel; this way safety and precise positioning of the wheel is ensured. Four gear wheels driven by belt are imprecise and work against each other.

Wheels are received beauty face up. A live roller conveyor advances the wheel to the product entry door of the radiation enclosure. X-ray tube is mounted above in-feed conveyor. Imaging system is mounted on the opposite side of x-ray tube. The belt-driven gripper can only accept wheels between 12” and 18” and up to 12” in width/height.

The entry door opens allowing the wheel to advance onto the robotic 4-axis manipulator (horizontal – along x-ray beam, vertical, tilt and rotation). The wheel is identified, and the product code is chosen from a pre-programmed wheel styles.

Movement of the wheel into the pre-assigned inspection sequence begins as soon as the wheel is positioned on the manipulator. Simultaneously, x-ray energies automatically adjust to pre-programmed levels for the wheel’s orientation and presentation to the imaging system.

Upon completion of the inspection sequence, a “reject” or “accept” status is decided.

The inspected wheels are released through the product door onto the exit conveyor. The machine from Fig. 4 is similar to the machine described in Offenlegungsschrift DE

Please refer to pictures 5 and 6 and 7. The wheels are brought to the radiation enclosure on an in-feed conveyor with a selector. After passing a selector, a single wheel is transported to the in-feed radiation lock where the adaptive wheel identification device is located. The wheel identification system identifies the wheel. Machine control assigns the actual wheel to a pre-programmed type and downloads all wheel data including the quality control specifications. After passing the radiation lock, the lead in-feed slider opens and the chain manipulator grips the wheel on the lower rim flange (opposite of beauty face up, see Fig. 6) and brings it to the x-ray beam to a specific location (chain rotation in the same direction). The x-ray images are taken and operator or software examines the x-ray images according to the quality control specifications. The image intensifier system (top) and x-ray tube with the shutter (bottom) are mounted on a C-arm.

In order to penetrate every inspection area of the wheel during the rotation, the C-arm tilts (-70°) and moves vertically synchronously (300 mm) around the wheel. The rotation is executed using chains that drive the wheel in opposite directions. After each test step, operator or software makes either a “PASS” or “FAIL” decision.

Please refer to Fig. 5, 6 and 7. This system is inherently complex. The entire machine is based on a chain drive system. The chains in the system are susceptible to wear, sagging, and stretching. The system also requires frequent cleaning and lubrication to operate properly. These factors make chains a poor choice for any machine where accuracy is required. In addition, the chains also have trouble gripping the wheel properly, and wheel slippage occurs. Slippage causes problems for the defect recognition system because if the wheel slips, it is possible that an area of the wheel may not be inspected, or to
compensate, the wheel may need more indeces to ensure proper inspection of the wheel, resulting in an increase in the inspection time. The machine is also quite large, requiring a large open space to install. The improved version of this generation addresses the problem of having the wheel slip by replacing the drive chains with a gearbox system (Fig. 7). Although better than the original, it is still very complicated, and still uses chains to transport the wheels onto and off from the device.

International Patent Application PCT/EP02/11644

This application is based on German Patent Application No. 101 53 379.9 by Fraunhofer Gesellschaft (Thomas Wenzel, Dr. Randolf Hanke and Mr. Ashley Stone).

The machine on Fig. 8 is built by Becker, Germany according license agreement with Fraunhofer Institut für Integrierte Schaltungen in Führt/Erlangen. The used double gear train is based on earlier development by Francis Horvath and Ashley Stone. Dr. Hans Müller (FhG) and Werner Michaely (Becker) visited Francis Horvath and Ashley Stone on the end of April 2001 to see and try gripper from Fig. 9 (build in 1998 and 1999).

DP500 is similar to machines on Fig. 5, 6, 7 and 8 and uses double gear train to grip and hold wheel.

Instead of shaft-driven (Fig. 1), chain-driven (Fig. 2), belt-driven (Fig. 3 and 4), direct drive (Offenlegungsschrift DE 3115735 A1 dated 18.4.1981) Francis Horvath and Ashley Stone introduce first time worldwide gear train to rotate and hold wheel.

The gripper wheels were designed with a larger contact surface and a contour better suited to the wheels being cast. They were hardened to extend the service life, and were made from off-the-shelf gears, reducing the cost. The drive system was changed from...
shaft, chain, direct drive and belt to a sealed gearbox (Fig. 9), eliminating the need for maintenance, lubrication or replacement of the chain. All of these improvements made the gripper much more robust and precise.

In June 2000 Francis Horvath and Ashley Stone retrofitted the gripper from Fig. 3 (belt-drive) with gearbox (Fig. 10) eliminating parts seen on Fig. 11.

The inspection of larger parts in an automated manufacturing environment using x-ray means poses a number challenges to the quality control professional. For example, there is a need to non-destructively inspect automobile wheels for internal flaws. Automobile wheels are cast or forged from alloys of aluminum and magnesium. A common flaw in these wheels is the presence of occlusions or gas voids in their internal structure. It is well known that such defects in objects rotating at high speed may cause catastrophic failures. Therefore, it is vital to identify such defects and reject any wheel found to contain them. Automobile wheels by their nature are heavy and difficult to manipulate using simple grappling devices or pincers. Therefore, prior art devices adapted for the manipulation of small lightweight objects such as turbine blades and circuit boards cannot be used in an automated wheel manufacturing process. Additionally, the x-ray scanning head and detection device must be sufficiently sized to swiftly and completely scan the object to ensure that flaws are detected. Wheel rims used in the automotive industry include, for aesthetic reasons, many shaped and contoured surfaces. Therefore it is important to be able to manipulate the wheel in a variety of orientations to ensure that any flaws contained in spokes or other aesthetic features are detected. However, wheel manipulations devices can be very complex requiring such mechanically unreliable components as chain drives and belt drives. The use of these complicated mechanical
components adds to the expense of manufacturing and maintaining the inspection unit.

Finally, operator operated inspection stations require significant resources for operator training in recognizing faults on x-ray images. Operator reliability may be less than desired.

The known inspection devices cannot meet the requirements for the type of x-ray inspection for automobile wheels in an automated manufacturing environment using a simple wheel manipulation device. The known inspection devices are better suited to smaller and lighter objects. Therefore there is an ongoing requirement for an x-ray inspection system that is adapted for use in an automated heavy part-manufacturing environment.

SUMMARY OF THE INVENTION

MAXIwheel™ – Machinery for Automatic X-ray Inspection of wheels (Please refer to Figures 8, 9, 10, 11,12,13,14 and 15).

The lightweight manipulator has a minimum number of moving parts for maximum efficiency. It’s very robust, simple to produce and maintain. The manipulator consists of a tilt table and a “C” arm with variable geometry in regards to table for x-ray tube and/or imaging system. The manipulator has 6 AC servo axes of movement: 2 tilt axes (table and C-arm), 2 wheel rotation axes (if one fails), vertical axis (magnification) and horizontal axis (C-arm with x-ray tube (incl. shutter and filter) and image intensifier (9” or 12”)). The tilt table and the “C” arm tilted by shaft mounted drives. The wheel is driven by two pairs of gear wheels (two angled gear boxes in V-shape). The optimum
gripping geometry for small and big diameter wheels is possible using V-shape gear-boxes arrangement. The wheel is gripped on lower rim flange (Fig. 8) instead of upper rim flange (Fig. 9). No belts or chains to adjust and lubricate.

The manipulator has a very small footprint (1500mm x 1500mm). The wheel transfer in and out is by gravity and as short as possible. No chain to adjust or belt to slip, and no drive. The two swing out bumpers absorbs the kinetic energy of the wheel, the bumpers swing out, and the wheel slips in on a sloped frame to guide the wheel rim into the fixed drive wheel and an air cylinder operated frame lifts the back of the wheel into position to close the gripper arms, retract the lift frame, swing out the bumpers and rotate the wheel for inspection. In order to position the wheel into the right orientation, the table and the “C” arm can be moved independently to reduce the positioning time.

Optimum Sequence of Inspection

1. 17⁰ slope slide in, immediate spoke inspection
2. Horizontal position, immediate hub inspection
3. Tilt 28⁰ rim inspection

then release gripper arms and wheel slides out to the “reject” or “accept” conveyor.

Repeat the inspection sequence again. In each of above positions (1, 2 or 3) the complete C-arm can be moved 300mm horizontally to allow tilt around defects between center and edge of inspected wheel.
Wheel Sizes (seen from in-feed side)

Group 1 (driven by 2\textsuperscript{nd} two pairs)  Group 2 (driven by 1\textsuperscript{st} two pairs of V-shape angled gear box)

13”        17”
14”        18”
15”        19”
16”        20”

In accordance with a preferred embodiment of our invention there is provided an fully automated x-ray inspection apparatus for the inspection of light alloy wheels that employs gravity to move the wheel under inspection (WUI) into and out of the field of the x-ray inspection device thereby eliminating the need for costly and complicated mechanical moving means and increasing the speed of inspection of the WUI. The invention further relies on a single split door for in-feed and out-feed of WUIs into and out of the inspection cabinet. This is reduces complexity of the device and significantly increases the inspection cycle time for each WUI. The invention comprises means for receiving a WUI from the manufacturing line; means for enclosing the WUI in an x-ray impenetrable enclosure; means for holding and manipulating the WUI in several orientations; an x-ray emitter and a camera for x-ray imaging of the WUI. The invention further includes control means to control the operation of the invention. Automatic means are provided capable of detecting flaws in the x-ray images received from the imaging device and rejecting the WUI based on those images.
The WUI manipulation means is adapted to grasp, hold, rotate and tilt WUIs of varying widths and diameters. The movement of the wheel manipulation means and the x-ray scanner/camera are coordinated and automated by control means.

OBJECTIVES AND ADVANTAGES OF OUR INVENTION

Advantages of the disclosed invention described above are:

a. to reduce the number of mechanical components in wheel x-ray inspection devices;
b. to rely upon gravity to move the WUI in and out of gripper;
c. to rely upon a single horizontal split in-feed/out-feed door in the inspection cabinet rather than two or more doors;
d. to reduce the cost of manufacturing, purchasing and maintaining an x-ray inspection device;
e. to increase worker safety during the inspection process;
f. to reduce the overall mechanical complexity of such machines by relying upon gravity to transit the WUI through the inspection station;
g. to increase the rate at which wheels may be inspected and increase the overall efficiency of wheel manufacturing process;
h. to reduce the foot print of the inspection device on the factory floor; and,
i. to lower labor costs associated with inspecting wheels.

j. all geared system made for 24/7 operations for minimum 10 years usage.
k. to reduce cycle time using the shortest possible wheel transport way.
I. to reduce cycle time by dividing tilt movement in two tilts (C-arm and wheel table).

Still further objectives and advantages of my invention will become apparent from a consideration of the ensuing description and drawings.

DESCRIPTION OF THE FIGURES

Figure 12 is a diagram of the tilt table.

Figure 13 is a diagram of x-ray emitter and camera associated with the tilt table.

Figure 14 is a Gearbox section A-A (used in V-shape arrangement).

Figure 15 is 3D view of in-feed side.

DETAILED DESCRIPTION

The invention comprises four major sub-systems. The first sub-system comprises means for holding, rotating and tilting the WUI in a variety of different positions so that the x-ray imaging sub-system can take a plurality of images of the WUI at different viewing angles. There is a second x-ray imaging system comprising an x-ray source, an opposing x-ray imaging camera. Thirdly there is a control sub-system that controls and coordinates the movement of the tilt table, the rotation of the WUI and the movements of the x-ray subsystem throughout the inspection operation.

Finally there is a flaw determination sub system that is capable of either accepting the WUI or detecting flaws in the WUI and rejecting the wheel from the manufacturing line.
Receiving and Manipulating Wheels

Referring to Figures 12 and 13 there is shown one embodiment of our invention (10) used for receiving WUIs (12) and manipulating WUIs during the inspection cycle. The wheels are received from the manufacturing line into an inspection cabinet (14) in which our invention is located. The inspection cabinet is impermeable to x-rays for worker safety. The wheels are received with their “beauty face” up. The “beauty face” is the outboard face of the wheel once mounted in the automobile (upper wheel flange). The wheels are transported into the inspection cabinet through a single in-feed/out-feed door (16) by means of a live roller conveyor. The use of a single split door for in-feed and out-feed eliminates the need for two doors and controllers to coordinate the operation of the doors. As well the use of a single split door increase the open and closing operation of the door and thereby reduces the wheel inspection cycle time. Transit through the inspection cabinet is accomplished by gravity. From the inspection cabinet feed door to the inspection station there is a free-roller conveyor (18) sloped downward at an angle of 17 degrees. This slope is sufficient to motivate the wheel by gravity along the free-roller conveyor to the inspection station (20). This eliminates the need for chain drives and other such motorized equipment to motivate the wheel between the feed door and the inspection station.

The invention comprises a horizontal base plate (22) for mounting the inspection device to the factory floor and two vertical plates (24 and 26) fixed to either side of the base plate. The base plate and side plates are sufficiently resilient to support the
tilt table (10) and x-ray inspection device (30) resist forces caused by movement of these components.

The tilt table (28) comprises a flat surface (32) for receiving the WUI (12) and for supporting the WUI before and after the inspection cycle. The tilt table mounts between the two vertical and parallel side plates (24 and 26) by way of two pintles (34 and 36) that are co-axial and fixed to opposite sides of the tilt table near its centre of gravity. At least one of the pintles (36) is motorized (38) to transmit rotational movement to the table through a transmission (40) to the pintle (36) by way of a suitable gearing. The amount of tilt imparted to the table by the motor is controlled by the control means of the invention. The movement of the tilt table is pre-programmed and coordinated with the rotational movement of the WUI and the movement of the x-ray imaging device.

The tilt table (28) mounts a number of operative components the function of which will become clear in the following discussion. The tilt table comprises means for stopping the WUI that slides onto the surface of the table at the approximate centre of the table. Means for stopping the WUI at the inspection station comprises a pivoting arm (42) wherein one end of the arm (44) is pivotally attached to the tilt table and the other end of the arm (46) fixes a bumper (48) made from shock absorbing resilient material. When the WUI enters the inspection cabinet the stopping means is pivoted by an angle of 90 degrees (50) so that the axis of the arm (52) is perpendicular to the axis of movement of the WUI (54). The arm (42) is long enough so that the bumper (48) is located proximate to the axis of movement of the WUI so that the WUI will contact the bumper along the WUI’s axis of movement. The bumper may also have a
resilient skirt (56) at its contact end to further cushion the contact of the WUI and provide for frictional engagement of the bumper with the wheel to prevent bouncing. Once the movement of the WUI is stopped within the inspection station the bumper arm will retract 90 degrees (50) so that the arm (42) is parallel to the axis of movement of the WUI.

The tilt table further comprises means to lift the WUI so that the bottom rim of the WUI engages the drive wheel (56), the guide wheels (58, 60 and 62) and the wheels (64 and 66) on the ends of the gripper arms (68 and 70). Once the WUI bottom rim is lifted into position and engaged by the wheels the lifting device retracts from the x-ray imaging device field of view.

As noted above, the tilt table also comprises at least one drive wheel (58) for engaging the bottom rim of the WUI and for rotating the WUI a predetermined amount to facilitate inspection. The drive wheel is driven by a drive means comprising a sealed gear train. The motion of the drive wheel is controlled by the invention control means so that the desired views of the WUI can be obtained and the wheel rotation can be coordinated with the tilt of the table and the movement of the x-ray device. The circumference of the drive wheel is adapted with a furrow (72) to receive the outer circumference of the lower rim (74) of the WUI. The drive wheel engages the lower rim of the WUI in a frictional engagement so that sufficient traction is generated to rotate the wheel. The drive wheel is made from metal or a suitable resilient polymer and may have additional features to improve the frictional engagement with the WUI rim such as gear teeth or bevels.
The table also comprises a plurality of guide wheels (58, 60 and 62) that are identical to the drive wheel but are not driven. As noted above, the WUI is lifted by cylinder, so that the lower rim of the wheel is engaged with drive wheel and guide wheels. The guide wheels are adapted to ensure that the WUI remains in a stable position during inspection and that, during WUI rotation, the WUI remains properly located on the tilt table.

Also mounted to the surface of the tilt table are means (80 and 82) to further hold the WUI firmly in an abutting relationship to the drive and guide wheels so that maximum traction between the drive wheel and the lower rim of the WUI. These means include the two-gripper arms (68 and 70) having a first (84) and second (86) ends. The first end (84) of the arm is pivotally attached to the table (28) and the other end of the arm (86) is free. The free end of the arm mounts a free rolling guide wheel (64 and 66) to engage the lower rim of the WUI in the same fashion as the drive wheel and guide wheels. At the midpoint (88) of each arm there is a pivoting attachment to a reciprocating member (90) that is reciprocated by an air piston (92) attached to a suitable supply of compressed air. The air pistons operate in tandem. When actuated the air pistons fill and push the reciprocating members outwards. One end of the member is pivotally attached to the gripper arm at the approximate midpoint of the gripper arm and forces the arm open so that the guide wheel on the end of the arm is to the side of the table. This permits a WUI to move onto and off of the tilt table. Once the WUI has slid onto the table the WUI is lifted by lifting means to a height suitable for engagement with the wheels on the gripping arms. Air is then injected into the opposite end of the cylinder and the gripper arms are then forced into
the centre of the tilt table by the two pneumatic cylinders. The guide wheels on the ends of the arms are in firm frictional engagement the lower rim of the WUI. As shown in the Figure 12, the gripper arms are adapted to accommodate a variety of WUIs of different diameters (78). Once the WUI is on the tilt table and the gripper arms are engaged the WUI will be held rotatably fixed so that the table can tilt without the WUI moving. Once the inspection is complete the door of the inspection cabinet opens and the tilt table tilts 28 degrees. The gripper arms are extended so that the WUI slides from the table onto an exit conveyor (94). The exit conveyor slopes at an angle of 28 degrees downward from the surface of the tilt table. In this way, gravity is relied upon to remove the WUI from the inspection cabinet. If the WUI is flawed and has been rejected then it is directed by directing means to a recycling area for return to the foundry (96). When an acceptable wheel leaves the inspection cabinet it is directed by directing means to a conveyor for further processing and finishing (98).
X-Ray Device

Referring now to Figure 13 there is shown the x-ray device (30) of one embodiment of our invention. The device comprises an x-ray emitter functionally located above the tilt table (28) so that the beauty face of the WUI is within the scanning field. An x-ray camera (102) is functionally located below the tilt table (10) and co-axial to the x-ray emitter. The x-ray emitter and the x-ray camera are linked by a pivoting frame means (106) so that they can be tilted and moved horizontally on the slider (107) on frame (110) in tandem such that the emitter and camera always remain co-axial. The frame has a substantially “C” shape with the tilt table (28) pinned (36) for rotation within the arms of the “C” frame. The x-ray emitter (100) provides a highly focused x-ray beam that is capable of penetrating the WUI. High energy x-rays between 50kV and 130kV provide a sharp image but other powers of x-ray emitters may be used. The x-ray emitter includes suitable shutters to control exposure and filters to harden x-ray beam. The x-ray camera (102) provides an x-ray image of the WUI.

The frame is dimensioned so that that the tilt table will not interfere with the pivoting motion of the frame during the inspection cycle. The frame comprises a first bottom horizontal member (110) located below the tilt table. The horizontal member has two ends. At one end, the x-ray camera (102) is fixed to horizontal slider (107). At the other end, the horizontal bottom member is fixed to a vertical member (112) having two ends. One lower end of the vertical frame member is fixed to the horizontal slider (107) and the upper end includes a pin (118) to adjust vertical axes manually or using motor (108) both mounted on the frame (110), which can be tilted. The pin is
attached to a motor and transmission so that a rotating motion can be imparted to the frame. The motor is controlled by control means so that the movement of the frame is coordinated with the movement of the table and the rotation of the WUI.

The vertical member (112) of the frame extends higher than the tilt table (28).

Attached to the end of the vertical frame member is a sloped frame member (120) extending upwards and away from the axis of the vertical frame member towards the axis of the camera (100). The sloped member provides sufficient clearance over the tilt table to avoid any interference of movement between the tilting table and the pivoting frame means. The frame means further includes a top horizontal member (122) having two ends. One end is attached to the sloping frame member and the other end holds the x-ray emitter over the tilt table so that the axis of the WUI and the axis of the camera are generally co-axial. It can be seen by the combination of the tilting table and the rotating frame means that the WUI may be manipulated various ways to ensure complete coverage of the WUI for x-ray scanning to detect all flaws in the WUI.
Wheel Inspection

Once the WUI is inside the inspection chamber and gripped firmly on the tilt table, the inspection cycle commences. The wheel is then placed in a variety of orientations as determined by the scanning program and the wheel is scanned. The x-rays penetrate the wheel and are received by the x-ray camera opposite the emitter. Images from the camera are relayed to a display placed in front of the operator for viewing in real time. Flaws in the wheel will be readily apparent to fault detection software.

Acceptance and Rejection of Inspected WUI

If the fault detection software does not find any flaws in the WUI, the WUI is accepted and released from the tilt table onto the exit conveyor. Directing means will direct the accepted WUI for further processing and shipping. If the WUI is rejected because of a detected flaw the WUI the WUI is released from the tilt table and directing means will direct the rejected WUI to the foundry for recycling.
Command and Control

Simple command and control means are provided for our invention to control the movement of the device and to process the images. The invention may be controlled using a PC with a suitable amount of processing power. The PC may be conveniently preprogrammed so that the movement of the x-ray device, the tilt table and rotation for the wheel are easily coordinated for a complete scan of the WUI. Images are captured by the camera and transmitted digitally to the analysis software on the PC. The software will review the images and based on heuristics common to such fault detection software will identify WUIs that are flawed and need to be rejected. Operator override is possible on all functions of the invention.

Although this description contains much specificity, these should not be construed as limiting the scope of the invention by merely providing illustrations of some of the embodiment of the invention. Thus the scope of the invention should be determined by the appended claims and their legal equivalents rather than by the examples given.
CLAIMS

What is claimed is:

a fully-automated, all geared, low maintenance, heavy duty, very tough x-ray inspection system for light alloy wheels (cast automotive wheels) comprising:

1. an inspection cabinet impermeable to X-rays for containing the inspection system;

2. gravitational means for transporting the wheel under inspection in to and out of the inspection cabinet;

3. means for holding, rotating and tilting a wheel under inspection in a variety of different positions for optimum x-ray scanning;

4. means for coordinating and controlling the movement of the means for holding, rotating and tilting the wheel and x-ray emission means so that they move cooperatively the result being full x-ray coverage of the wheel under inspection;

5. means for x-ray image analysis for automatically detecting flaws in the wheel under inspection including means for rejecting flawed wheels.

6. prior sealed gear train to hold and rotate wheel on upper rim flange (face up side, see Fig. 9 and Fig 10)

7. sealed gear train to hold and rotate wheel on lower rim flange (Fig. 8, 12 and 15) and

8. V-shape (Fig. 12, 14 and 15) of double gear train for optimum gripping geometry (close to 45°, 135°, 225° and 315°)

SUBSTITUTE SHEET (RULE 26)
Fig. 4

1. Radiation shielded enclosure
2. 4-axis chain manipulator with 2-axis C-arm
3. X-ray source
4. Image intensifier System
5. X-ray life image monitor
6. AWIS monitor
7. AWIS camera
8. Touch screen operator interface
9. In-feed conveyor
10. Accept wheels
11. Reject wheels

Fig. 5

Fig. 6

SUBSTITUTE SHEET (RULE 26)
Fig. 13