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FLEXIBLE MANUFACTURING CELLS FOR WAFER MANIPULATION AND CONTROL IN SOLAR PANEL MANUFACTURING

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Abstract: *The paper presents the main results of a preliminary design study developed for two flexible manufacturing cells for wafer manipulation in solar panel manufacturing process. Based on the customer's specific requests, the flexible manufacturing cells have been developed for performing complex tasks, supplementary to robotic wafer's manipulation (wafer's loading / unloading), wafer's random position and orientation identification (before loading) being available as well as wafer's diagnosis / integrity checking (before and after processing in the specific manufacturing equipment) being available too.*
Keywords: *flexible manufacturing cell, industrial robot, wafer, manipulation, control, solar panel*

1. INTRODUCTION

Present paper presents a design study that has been developed by a Romanian research team, for a German customer directly involved in (solar panels) wafer's processing equipment manufacturing and sales. As background for starting preliminary discussions for grounds of further design study approach the customer has forwarded one generic proposal for a wafer processing manufacturing line, including: WFS (wafer's processing equipment) and two FMC (flexible manufacturing cells) for wafer manipulation in manufacturing process, partially equipment & cell layout being presented in Figure 1 [1]. Full structure of manufacturing line includes: the outdoor section (wafer slicing equipment and wafer transporting system - conveyor belt) the front section (robotized FMC for wafer diagnosis & loading into "cassettes" processing device, "cassettes' conveyors and respectively a special purpose machine for "cassettes" loading into "frame" processing devices), middle section (wafer processing equipment) and rear section (a special purpose machine for "cassettes" unloading from "frame" processing devices, "cassettes' conveyors and respectively a wafer diagnosis & unloading robotized FMC).

2. SPECIFIC APPROACHES TO FMC DESIGN [1],[2]

According to the above-presented preliminary specification, the drawing main tasks to be performed in the two robotized FMC have been initially specified by customer as follows:

- wafer's breaking detection and outbreaks of corners;
- wafer's position and orientation on the belt detection and robot effector trajectory/ orientation correction;
- wafer's handling required speed 42 wafers/min;
- avoid contacts between robot's end-effector and manufacturing device's side walls / wafer's edges.

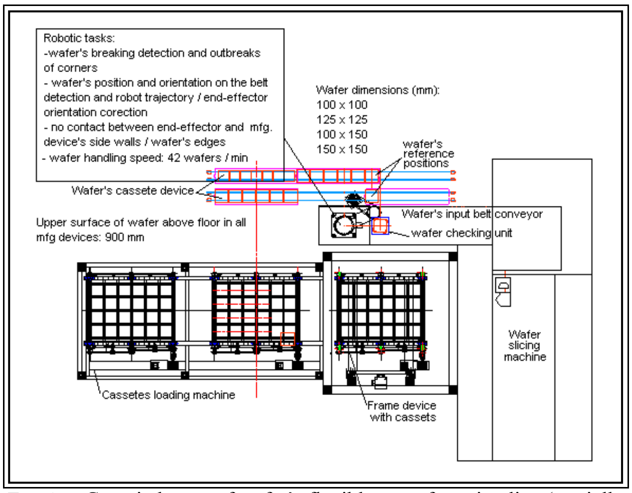

Fig. 1. Generic layout of wafer's flexible manufacturing line (partially view) including: wafer slicing equipment and transporting system - belt conveyor, robotized FMC for wafer diagnosis & loading into "cassettes" processing device, conveyors and special purpose machine for "cassettes" loading into "frame" processing devices

- avoid contacts between robot's end-effector and manufacturing device's side walls / wafer's edges.

For this purposes, two different approaches will be presented hereunder (both of them being proposed for solving the same problems related to wafer loading / unloading process automation, by means of two specific Wafer Positioning System / WPS)[1]:

- the WPS-01 System solution (based on the proposed customer's approach for the problem solving, considering own studies and preliminary experience);
- the WPS-02 System improved solution (a new design approach, proposed by a Romanian research team), having the following main advantages:
- increased productivity by using a wafer diagnosis procedure directly on the transparent - below illuminated - belt of the conveyor, eliminating the need to handle the wafer to a separate illuminated plate;
- sole diagnosis procedure by including all the operations required for ideal position and rotational deviation correction as well for maximum achievable precision wafer integrity check.

2.1 WPS fundamentals and basic specifications

Following the preliminary technical & financial analysis the following issues have been identified as WPS fundamental issues and basic specifications:

- All components must be certified and industry accepted;

- Increasing speed and productivity through parallel processing solution with event based synchronisation;
- “Single Camera wafer’s complete diagnosis on the conveyor’s belt” technology, adopted due to the:
  - Price increases when using more than one camera (camera, lenses, interface board, cables, mount);
  - Possibility that the wafer may arrive crashed and in this case it can not be handled by the robot;
  - Random wafer localisation on the conveyor and necessity to retrieve wafer’s exact position and rotational deviation versus the conveyor’s longitudinal axis and the wafer’s fixed loading point;
  - Means for conveyor stopping solution in loading station need to be complementary defined by customer;
- Redundancy is preferable to be used wherever possible in order to increase system’s productivity and flexibility.

WPS-01 specific features: a.) general purpose belt conveyor supplied by customer; b.) identification of a wafer’s position considering rotational deviation up to 45 degrees (full scale); c.) non redundant system with non-existent wafer localisation and conveyor stopping solution provided by customer; d.) lower precision defect recognition, due to a contrast surface missing (or necessity of two robot handling cycles if the contrast surface is different of the conveyor’s one); e.) longer processing time cycles (see the cycle charts), lower productivity, medium global accuracy; f.) supplementary wafer presence checking at unloading port increases productivity by decreasing image processing tasks (eliminating them when no wafer is present in the cassette).

WPS-02 specific features: a.) transparent belt conveyor proposed by Romanian research team; b.) identification of a wafer’s position considering rotational deviation up to 45 degrees (full scale); c.) redundant high precision system using light barrier and camera, to stop the conveyor when wafer reaches camera visual field; d.) backlights underneath the transparent conveyor’s belt ensures wafer’s finest achievable defect recognition (0.05 mm cracks, maximum 5% corner’s / edge’s missing material), increase robot handling accuracy and allows programming of a single robot handling cycle; e.)parallel processing working cycle with increased productivity (lower processing time cycles) and highest global accuracy; f.) supplementary wafer presence checking at unloading port increases productivity by decreasing image processing tasks (eliminating them when no wafer is present in the cassette).

3. COMPONENTS OF THE WPS-01 AND WPS-02 SYSTEMS [1], [3], [4], [5]

Both WPS-01 and WPS-02 systems include as common components the following devices: a.)CCD digital camera, and C-mount camera lenses (Figure 2); b.)frame grabber card and interface cable (Figure 3); c.)industrial PC (Figure 4); d.) SCARA robot (Figure 5); e.)camera adapter to fit camera data interface; f.)camera, back light power supply-12V DC/2W power supply; g.)recognition software - run time license -; h.)Windows 2000 - operating system license; i.)miscellaneous accessories - mounting, lights, etc; j.)infrared barriers (emitter and receiver)-detects wafers missing from the cassette at the unloading port; k.)transparent belt conveyor and backlight illuminating plate (adapted for transparent belt conveyor), (Figure 6); l.) multiple point light barrier-sensors for precise identification of the wafer to provide exact positioning in the camera’s area; m.) multiple point light barrier - source for provide a light source for the sensors to sense wafer presence and to allow position and rotational deviation computation.

Fig. 2. CCD digital high-resolution mega-pixel camera; high-speed 10 bit LVDS interface; industrial environment ready, and C-mount camera lenses, 12–36 mm focal length lenses, 3x variable zoom [3]

Fig. 3. Frame grabber card, digital frame grabber board, 32 bit LVDS camera interface, PCI high speed interface and frame grabber to open end high-speed data transfer cable [3]

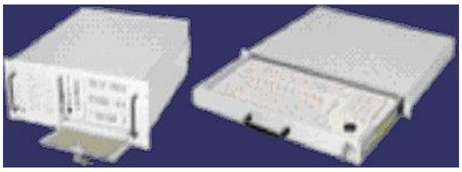

Fig. 4. Industrial PC, dual hot-swap power supplies (2 x 400W), keyboard with trackball; including monitor in 19” rack format, all modules 19” rack format [1]

Fig. 5. SCARA robot, 650mm reach; over 5 m/s combined velocity, latest generation controller, advanced language development, easy interfacing with controlling unit (industrial PC), world-wide service and support centres available [4]

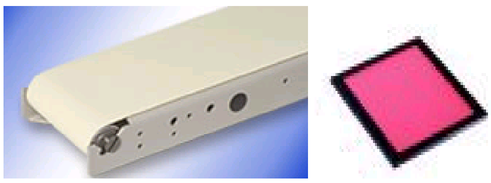

Fig. 6. Transparent belt conveyor, variable speed, remote controlled by the industrial PC, industrial environment, low profile (below 2 inches

height) and backlight illuminating plate (adapted for transparent belt conveyor), LED based high illumination, industry standard product [5]

4. ANALYSIS OF THE LOADING WORKING CYCLE FOR WPS – 02 SYSTEM [1]

The architecture of the loading cell is presented in Figure 7 and two different sequences of the working cycle are presented in Figure 8.

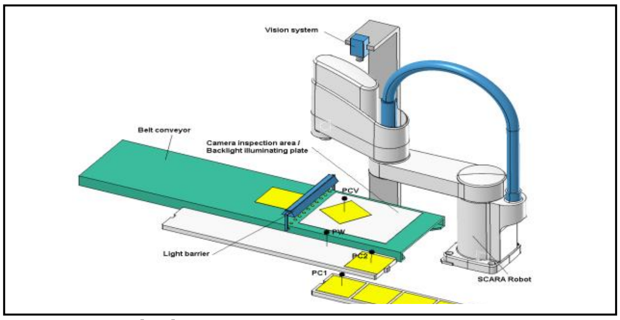

Fig. 7. WPS-02 loading FMC

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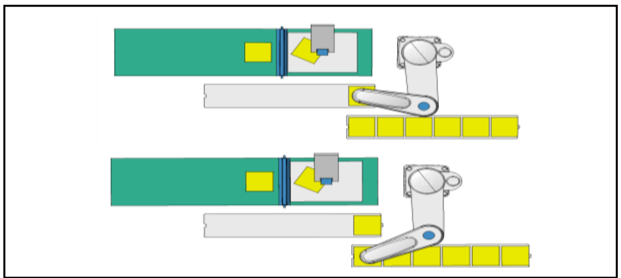

Fig. 8. Different sequences of WPS-02 loading FMC loading cycle.

4.1 Robot tasks and loading cycle

The wafer loading manipulation cycle of the robot includes movements between 4 key points:

- PC1 – the point vertically aligned with the centre of the wafer loading position in cassette #1;
- PC2 – the point vertically aligned with the centre of the wafer loading position in cassette #2;
- PCV – the point vertically aligned with the centre of the wafer from the conveyor (the frame that defines the complete position and orientation of this key point will be provided by the vision system);
- PW – the waiting point (the robot will stop and wait in this particular point the completion of the wafer position / orientation detection process).

From these above-mentioned points PC1, PC2 and PW are fixed and defined for the entire manipulation cycle. Only the point PCV will be provided to the robot controller dynamically by the vision system according to a new detected wafer position / orientation (if the wafer is good and ready to be loaded in the wafer cassette).

A pick or place operation assumes that the robot's end-effector descends from a key point until the vacuum grasping device enters in contact with the wafer surface and securely grasp or release the wafer and then the robot end-effector moves back in the key point. A pick operation is possible only in the PCV point and a place operation is possible only in PC1 and PC2 points. As result, the robot's wafer manipulation cycle is as follows: 1) at the start moment (t=0 s) the robot is positioned in PCV and the wafer position / orientation is fully defined by the vision system; 2) the robot executes wafer pick operation and comes back in PCV point; 3)the wafer is transferred in PC1 or PC2 point; 4) the wafer is placed in the cassette #1 or #2 and robot is moving back in PC1 or PC2 point; 5) the robot's arm is moving to PW point and waits for new wafer position / orientation information provided by vision system; 6) the robot's arm is moving in the new PCV point that was provided as a result of the image processing; 7) the cycle is repeatedly executed.

4.2 Transparent conveyor belt features and tasks

The conveyor belt that we are able to provide has the following important characteristics:

- transparent belt ready to implement a backlight solution on the conveyor it self;
- possibility to implement a multiple points light barrier as a redundant rough wafer presence detection and conveyor control (this feature will reduce the image processing time and will result an increased overall system efficiency);
- in this version the vision system will complete the wafer integrity check and the precise determination of wafer position / orientation. The feed-back signal for conveyor movement control is provided by the multiple points light barrier;

The conveyor belt working cycle is as follows: 1) the conveyor moves until the wafer passes trough the light barrier entering the video camera field and stops; 2) the conveyor remains stopped for the time period required for image processing and wafer pick-up by the robot; 3)the cycle is repeatedly executed; 4) if a crashed wafer is detected, the conveyor continues the movement evacuating the wafer (or the parts) out from the system. In this particular case the robot will wait in the PW point the arrival of a new (good) wafer; 5) the working cycles are presented hereunder (for conveyor, robot and vision system) along with a complete time intervals evaluation.

Cycle 1: Manipulation of a wafer from conveyor to cassette #1:

ROBOT: Wafer pick-up from PCV: 0 s…0,2 s; Move from PCV to PC1: 0,2 s … 0,6 s; Wafer placing in PC1: 0,6 s … 0,8 s; Move from PC1 to PW: 0,8 s…1,2 s; Move from PW to PCV: 1,2 s …1,4 s; STOP 1,4 s…1,5s; CONVEYOR: STOP: 0 s … 0,7 s; Move until next wafer arrives in video camera's field of view: 0,7 s … 1,2 s; STOP 1,2 s …1,5 s.

VISION: STOP 0 s … 0,7 s; Image acquisition, processing and communication with robot controller: 0,7 s … 1,2 s; STOP 1,2 s …1,5 s.

Cycle 2: manipulation of a wafer from conveyor to cassette #2

ROBOT: Wafer pick-up from PCV: 0 s…0,2 s; Move from PCV to PC2: 0,2 s … 0,5 s; Wafer placing in PC2: 0,5 s … 0,7 s; Move from PC2 to PW: 0,7 s…1,0 s
Move from PW to PCV: 1,0s …1,1 s; STOP 1,1 s… 1,5s;

CONVEYOR: STOP: 0 s … 0,2 s, Move until next wafer arrives in video camera's field of view: 0,2 s … 0,7 s; STOP 0,7 s …1,5 s;

VISION: STOP 0 s … 0,7 s, Image acquisition, processing and communication with robot controller: 0,7 s … 1,0 s; STOP 1,0 s …1,5 s.

The analysis of the working cycles above presented in Figure 8 and its description offers the possibility to highlight a means of wafer manipulation time frame in the interval (1.25 – 1.40 seconds). At the same time taking into consideration that usually 0.2 – 0.3 seconds are required for image processing, an optimised parallel functioning of the three main subsystems integrated in this robotized application results due to the parallel video processing and robot movement.

5. ANALYSIS OF THE UNLOADING WORKING CYCLE FOR WPS – 02 SYSTEM [1]

5.1. Robot tasks and unloading cycle

The design of the unloading cell is similar (mirror disposal of the components) to the loading FMC. The wafer unloading manipulation cycle of the robot includes movements between 3 key points:

- PC1 – the point vertically aligned with the centre of the wafer loading position in cassette #1;
- PC2 – the point vertically aligned with the centre of the wafer loading position in cassette #2;
- PCV – the point vertically aligned with the centre of the wafer deposition location on the conveyor;

All these above mentioned points PC1, PC2 and PCV are fixed and defined for the entire manipulation cycle.

A pick and place operation assumes that the robot end-effector descends from a key point until the vacuum grasping device comes in contact with the wafer surface and securely grasps or releases the wafer and then the robot end-effector moves back in the key point. A place operation is possible only in the PCV point and a pick operation is possible in both PC1 and PC2 points. As result, the robot's wafer manipulation cycle is as following presented: 1) at the start moment (t=0 s) the robot is positioned in PC1 or PC2; 2) the robot executes wafer pick operation and comes back in PC1 or PC2 point; 3) the wafer is transferred in PCV point; 4) the wafer is placed on the belt conveyor and robot is moving back in PCV point; 5) the cycle is repeatedly executed.

A sequence of WPS-02 unloading FMC loading cycle are presented in Figure 9 (perspective & layout views).

5.2. General purpose conveyor belt tasks

The conveyor belt working cycle is as follows:1) the conveyor moves with an amount equal to the wafer size + an incremental distance between successive wafers; 2) the conveyor remains stopped until the robot places the next wafer on the belt; 3) the cycle is repeatedly executed; 4) if a crashed wafer is detected in the cassette #1 or #2 or the wafer is not even present in the corresponding pick-up location the robot wait in the PC1 or PC2 point until the cassette is indexed.

Below there are presented the working cycles (for conveyor, robot and vision system) along with a complete evaluation of time intervals.

Cycle 3: manip. of a wafer from cassette #1 to conv.

ROBOT: Wafer pick-up from PC1: 0 s…0,2 s; Move from PC1 to PCV: 0,2 s … 0,5 s; Wafer placing in PCV: 0,5 s … 0,7 s; Move from PCV to PC2: 0,7 s…1,0 s; Wafer pick-up from PC2: 1,0s …1,1s; STOP 1,1s… 1,5s.

CONVEYOR:STOP: 0 s … 0,8 s; Move until next wafer deposition position is available on the conveyor: 0,8 s … 1,4 s; STOP 1,4 s …1,5 s

VISION: STOP 0 s … 0,5 s; Image acquisition, processing and communication with robot controller: 0,5 s … 1,0 s; STOP 1,0 s …1,3 s

Cycle 4: manipulation of a wafer from cassette #2 to conveyor

ROBOT: Wafer pick-up from PC2 0s … 0,2s; Move from PC2 to PCV 0,2s … 0,5s; Wafer placing in PCV 0,5s … 0,7s; Move from PCV to PC1 0,7s…1,1s; Wafer pick-up from PC1 1,1s … 0,3 s; STOP 1,3s…1,5s.

CONVEYOR: STOP 0 s … 0,7 s; Move until next wafer deposition position is available on the conveyor 0,7 s … 1,3 s; STOP 1,3 s … 1,5 s.

VISION: STOP 0 s … 0,4 s; Image acquisition, processing and communication with robot controller 0,4s … 0,9 s; STOP 0,9 s … 1,5 s

The analysis of the working cycle presented offers a wafer unloading time frame in the interval 1.20 … 1.25 s.

6. CONCLUSIONS ON CROSS-ANALYSIS OF WPS-01 AND WPS-02

Cross analysis of above two sets of correspondent features of two WPS has been performed:

- the WPS-01 System solution (based on the proposed customer's approach for the problem solving, considering own studies and preliminary experience);
- the WPS-02 System improved solution (a new design approach, proposed by a Romanian research team).

As a result, main specific advantages offered by WPS – 02 have been highlighted below.

A new design concept of wafer control has been developed and implemented into an industrial application. The conveyor used is equipped with a transparent belt with a light screen underneath. This provides maximum contrast for reliable and finest achievable integrity diagnosis. It also eliminates the need to handle the wafer to a separate diagnosis post and increase productivity.

An increased productivity of the FMC has been obtained derived from:

- the system's ability to detect a good wafer with its ideal position and rotational deviation from a crashed one in only one step,
- a single diagnosis procedure using a high resolution digital camera, thus deciding to handle the wafer or just advance the belt and eliminate it.

A detailed description of the operations flow in WPS– 02 has been presented.

7. REFERENCES

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