

Piotr DOMANOWSKI¹
Andrzej WAWRZAK²

AUTOMATION OF THIN FILM DEPOSITION PROCESS BASED ON MAGNETRON SPUTTERING

This paper presents the structure of a flow processing line implemented in domestic industry and designed for thin film deposition over large surfaces in an atmosphere of argon and reactive gases. The design of the line has been developed based on original pumping cycle and magnetron sputtering control systems.

1. INTRODUCTION

Large-size glass panels with infrared reflective, transmission changing or conductive coatings are used both in construction and transport. These coatings are produced on specially designed batch and flow vacuum processing lines [1],[2]. Marine windows constitute one type of these large-size substrate materials. Modern glazing consists of glass panes with specific properties such as emissivity, reflectivity, colour, wettability, absorption of radio waves and others, that are produced using ion-assisted thin film deposition applied on pre-shaped and pre-sized float glass and tempered glass panels. The resulting panes are further assembled and laminated to form units with special optical and strength properties employed in soundproofing, electro-heating, fireproofing, bulletproofing as well as in providing variable levels of transparency. In order to perform the aforesaid operations a flow processing line was designed and launched with the intention of covering large-size surfaces with thin film coatings using ion-assisted magnetron sputtering technology.

2. THIN FILM DEPOSITION LINE DESIGN

The flow line for thin film deposition by magnetron sputtering made at the Bohamet manufacturing facility in Białe Błota enables the processing of panels, particularly glass,

¹ Faculty of Mechanical Engineering, University of Technology and Life Sciences in Bydgoszcz, Poland

² Department of Technical and Applied Physics, Nicolaus Copernicus University in Toruń, Poland

with the following dimensions: 2250 x 3210mm and a thickness ranging from 4 to 25mm [2]. The overall dimensions of the line, except for the loading and unloading tables, are shown in Fig. 1; whereas the practical implementation is shown in Fig. 2. The primary workpiece material processed on this line is marine glazing that differs significantly from the typical mass production glazing used by glass panel manufacturers. The processing also covers tempered glass panes which have to be given their specific shape prior to tempering.

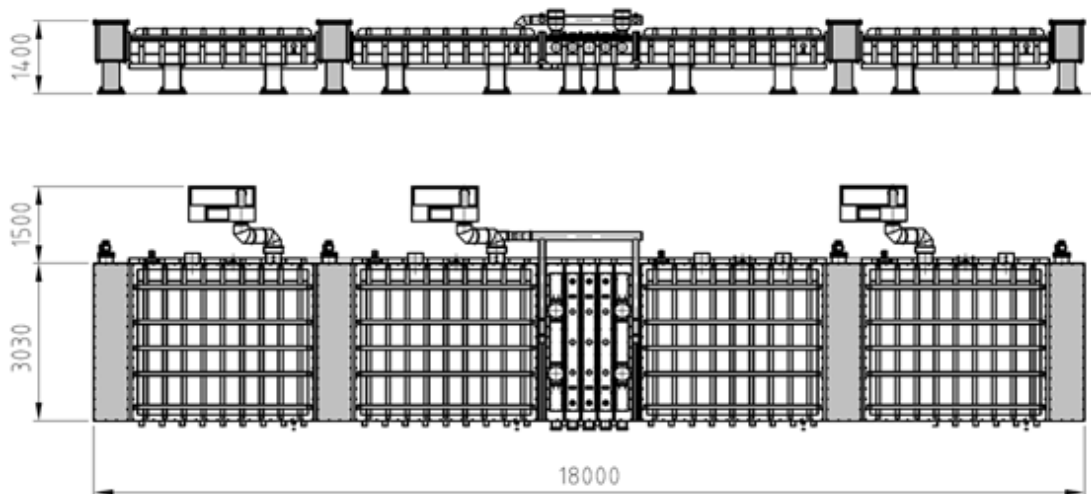


Fig. 1. The structure of the line for thin film deposition on glass panels



Fig. 2. General view of the line for thin film deposition on glass panels

The line for ion-assisted thin film deposition has a modular structure, where the same units (modules) are applied in functionally different parts of the line (Fig. 2). These units are: magnetron chamber (A), vacuum chamber (B), slot valves (C) and a modular roller conveyor (D). These modules are fitted with standardized flanges enabling any configuration within the line. The connection elements of turbomolecular pumps have the same dimensions as the magnetron sputter guns which makes it possible to install them at various points of the magnetron chamber - this is important in case of systems containing more than one magnetron sputter gun. Figure 3 shows a diagram of the completed line for thin film deposition on glass panels consisting of the modules shown in Fig. 4.

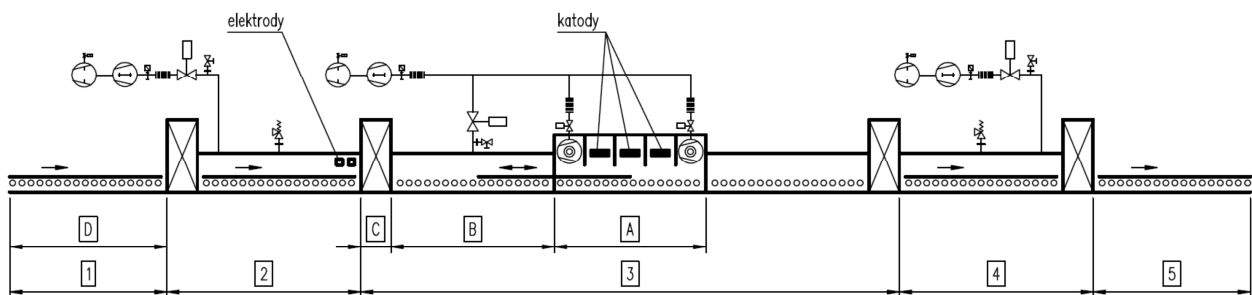


Fig. 3. Diagram of the line for thin film deposition on glass panels using magnetron sputtering technology: (1) loading table, (2) inlet chamber, (3) processing chamber, (4) outlet chamber, (5) unloading table, (A) magnetron chamber, (B) vacuum chamber, (C) slot valve, (D) roller conveyor

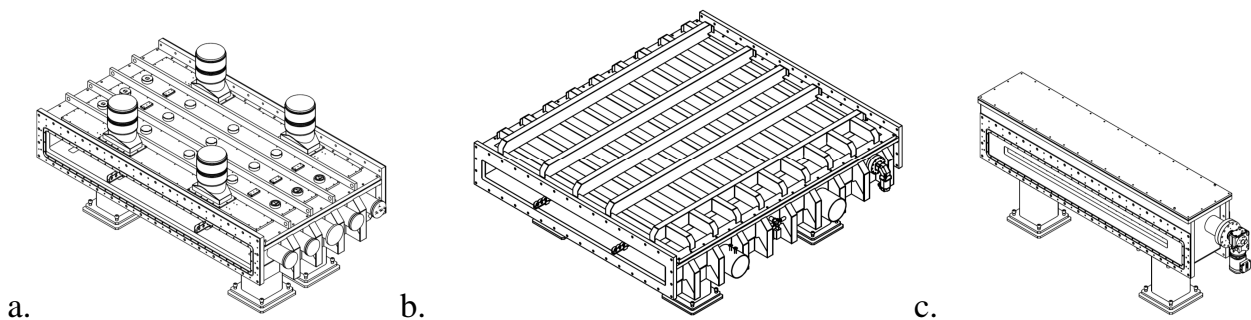


Fig. 4. Line modules: a) magnetron chamber, b) vacuum chamber, c) slot valve

2.1. DESCRIPTION OF THE LINE FUNCTIONAL MODULES

Feed table (1) is used for feeding glass panels into the inlet chamber. It is fitted with a roller conveyor (D) driven by a servomotor via duplex chain. Feeding rate is fully programmable in a range from 0 to 50mm/s. If thin films are applied onto smaller panels, these are placed on pallets. The feed table is fitted with an adjustable measuring rule which enables correct positioning of the panels on the table.

The inlet chamber (2) consists of a slot valve (A) and vacuum chamber (B). The inlet chamber is equipped with a roller conveyor (D) and, additionally, with electrodes used for

plasma cleaning of the panels being transported into the processing chamber (3). The inlet chamber is connected to a pump set: preliminary BW-200 pump and PR-2100 Roots pump manufactured by Tepro - Koszalin. These pumps create a vacuum of 1×10^{-3} mbar. Vacuum measurement is taken via TPR Pirani gauge heads. The chamber is aerated by nitrogen injection limited with a safety valve at a pressure level of 0.2 bar. The top cover of the vacuum chamber is removable for maintenance purposes.

The processing chamber (3) consists of two slot valves (A), two vacuum chambers (B) and one or more magnetron chambers (C). This chamber is under vacuum throughout the entire duty cycle and the passage between the two adjacent chambers: input and output is only possible after pressure equalization between the two. In order to ensure the required processing quality the magnetron chamber is pumped out to 5×10^{-5} mbar and then, after the addition of argon, a vacuum drop occurs to a level of 0.1 to 3×10^{-3} mbar and the magnetron sputter guns are activated. It is possible to have a programmable, bidirectional and multiple control over the movement of panels beneath the magnetron sputter guns. The magnetron chamber is fitted with four turbomolecular HiPace 1500U pumps from Pfeiffer Vacuum. Vacuum measurement is taken using TPR Pirani gauge heads and hot IMR cathode heads for lower vacuum levels. A WMP100x2500 rectangular magnetron has been applied for sputtering of the material, with the following dimensions: $2500 \times 3210 \text{ mm}^2$ and target thicknesses ranging from 4 to 25 mm. This magnetron has been designed specifically for this line at the Wrocław University of Technology (Faculty of Microsystem Electronics and Photonics) [3]. Three of these units are located over the moving substrates to ensure single and multilayer coatings in standard reactive processes (in the presence of reactive gas during sputtering, e.g. inert gas and N_2 , O_2 , hydrocarbons) and nonreactive processes (inert gas). The intensity of inflow is regulated using a Bronkhorst mass flow controller with an adjustment range of 18-900 sccm for argon and 6-300 sccm for oxygen and nitrogen. The nozzles supplying gas to the working area feed it indirectly through a diaphragm [4] which ensures even gas distribution over the entire length of the magnetron sputter gun. The magnetron sputter guns are powered by Dora Power System [5] power packs which constitute independent current sources. The power pack uses a resonant energy conversion system with quality factor stabilization. Between individual magnetron sputter guns there are diaphragms applied to minimize the impact of proximity of the guns to targets made of various materials. The magnetron chamber is covered from the inside with bolted protective screens minimizing service time during chamber cleaning.

The outlet chamber (4) does not differ significantly from the inlet chamber. What it only lacks is the plasma cleaning system. The unloading table (5) is a point where the glass panels are prepared for assembling or protective coating of the sputtered surface.

2.2. DUTY CYCLE

The movement of substrates through the line takes place in a sequential manner: after opening the slot valve (C) the panel is moved from the loading table (1) via a roller conveyor to the preliminary chamber (2), while the finished product (sputtered panel) leaves

the final chamber (4) onto the unloading table (5). At this time the sputtering process takes place inside the processing chamber (3). The module chamber (3) is pumped out to a final pressure level of 5×10^{-5} mbar, followed by determination of the conditions necessary for magnetron sputtering. Working gas or gas mixture is injected and the operating pressure is set at about 3×10^{-3} mbar. The magnetron sputter guns are activated.

Once sputtering has been completed in the processing chamber (3) and the volume of chambers (2) and (4) has been pumped out, the slot valves are opened between the processing chamber and the inlet and outlet chambers. In the next step the panels are simultaneously transported from the inlet chamber (2) to the processing chamber (3) as well as from the processing chamber (3) to the outlet chamber (4). Once the inlet (2) and outlet (4) chambers are aerated the cycle is repeated.

3. CONTROL SYSTEM DESIGN

The control of the aforesaid processing line is based on certain tasks that are executed in a parallel and synchronized manner, in accordance with the parameters defined by the user in the form of a so-called formula, and allow to implement the abovementioned operating algorithms of the line. These tasks are:

- chamber vacuum control process which includes the control of: rotary and Roots pumps, turbomolecular pumps, vacuum pump valves and aeration valves. The control of these components is based on information received from the valve sensors and vacuum pressure measurement sensors,
- panel transport control covering the control of conveyor servomotors allowing for the state of the panel position sensors,
- slot valve control (opening/closing), which includes driving motors, electromagnetic brakes and slot valve flap position sensors,
- control of the processing parameters of magnetron sputtering, which includes the magnetron sputter gun power supply control as well as proportioning and measuring the flow of processing gases (argon, oxygen, nitrogen),
- processing the commands of the line operator.

The components of the processing line control system, including the power supply systems, are located in four control cabinets:

- power supply cabinet containing: main switch circuits, protections, contactors, circuits separating and activating power supply to individual components of the line, phase control system, etc. This cabinet also contains soft start systems supporting the drive motors of rotary pumps type BW-200 and Roots pump type PR-2100 (3-phase induction motors with a power rating of 7.5KW),
- drive cabinet containing: frequency inverters regulating the drive motors of slot valves and servomotors controlling the glass transport drive motors. Owing to the use of frequency converters for powering the drive motors of slot valves (3-phase induction motors with a power rating of 1.5KW) it is possible to set the rate of opening/closing the valves, soft start and motor stop, overload control, etc. Glass panel conveyors are driven

by 3-phase AC permanent magnet synchronous motors with a speed of 5000revs/min. and a nominal torque of 3Nm, as well as Kinetix600 servomotors from Rockwell. The use of servomotors enables: conveyor speed control practically from zero to the nominal speed value (50mm/s), acceleration and deceleration profiling and panel movement in position mode, which is important during the process of deposition,

- magnetron sputter gun power pack cabinet containing: nine Dora Power System power packs (current sources). One magnetron in the processing line is powered by a set of three parallel connected power packs, allowing to power it at an approximate level of 30 KW (1000V, 30A). The input power control circuits allow presetting the amount of energy supplied to the magnetron and enable its remote control and monitoring both the current and the so-called circulating power whose value depends on the glow discharge plasma impedance mismatch with the power pack output circuit,
- PAC cabinet contains a ControlLogix programmable controller from Rockwell, PC type panel computer with touch screen, auxiliary automatic control systems and 24VDC power packs.

The ControlLogix controller is based on a cartridge design enabling flexible configuration of modules in accordance with the requirements of the controlled unit. In the processing line control system the controller has been configured as follows (Fig. 5):

- Logix 5561 processor module with a 2 MB memory,
- network modules:
 - EtherNet 10-100M Bridge Module, enables communication of the PAC controller over Ethernet, providing, in particular, communication with the PC type panel computer located in the controller cabinet, with HMI software installed, as well as with the computers used for starting and testing the system,
 - DeviceNet Bridge/Scanner Module, enables implementation of a local DeviceNet communication bus. This bus supports, among other functions, the communication with auxiliary operator panels located at the beginning and the end of the processing line,
 - Servo Module, 16 Axis SERCOS, which maintains communication with the Kinetix600 servomotors of the glass panel conveyors,
- discrete input/output modules type: 1756-IB32 and 1756-OB32, that enable a total read of up to 128 inputs and activation of up to 96 discrete outputs in a standard voltage of 24VDC,
- analogue modules: 1756-IF16, IF6I and 1756-OF8, which enable a read of up to 24 analogue inputs and setting of up to 16 analogue outputs.
- A 17-module cartridge allowing for a potential extension of the control system using additional unit cards.

4. PROCESSING LINE CONTROL SYSTEM SOFTWARE

The processing line software consists of a ControlLogix controller operating program and a program running on the panel PC which acts as the HMI for the operator. The software enables control of the processing line in three modes:

- automatic mode in which the sputtering process is carried out following the formula selected by the processing line operator,
- manual mode in which the operator selects and sets the parameters for individual operations, such as: vacuum pumping, chamber opening, panel movement, magnetron sputter gun activation; this is a dedicated mode for line testing and developing new process formulas,
- service mode enabling manual control and monitoring of all processing line components.

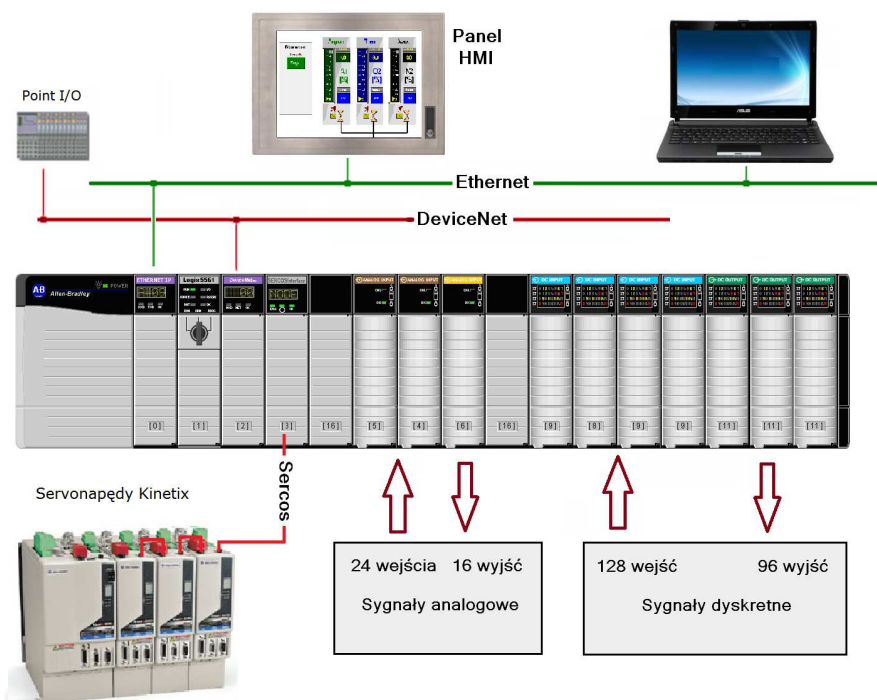


Fig. 5. PAC structure

The operating program of the ControlLogix controller was developed with the aid of a RSLogix_5000 software tool package from Rockwell using a ladder diagram language and structure text. The parallel vacuum chamber control algorithms, shown schematically in Figure 6, are executed in the automatic operation mode. The sputtering chamber control algorithm synchronizes the operating algorithms for other chambers. The procedures for vacuum measurement and working gas proportioning during the sputtering process, as well as the testing procedures for inadmissible and emergency conditions, are also implemented as parallel processes.

The deposition algorithm is executed according to the formula selected by the processing line operator, which contains the required process parameters such as:

- the number of substrate feed cycles through the sputtering chamber,
- the required pressure of processing gases (argon, oxygen, nitrogen),
- the rate of movement for the subsequent feed cycles,
- the effective (or circulating) power of magnetrons in individual cycles.

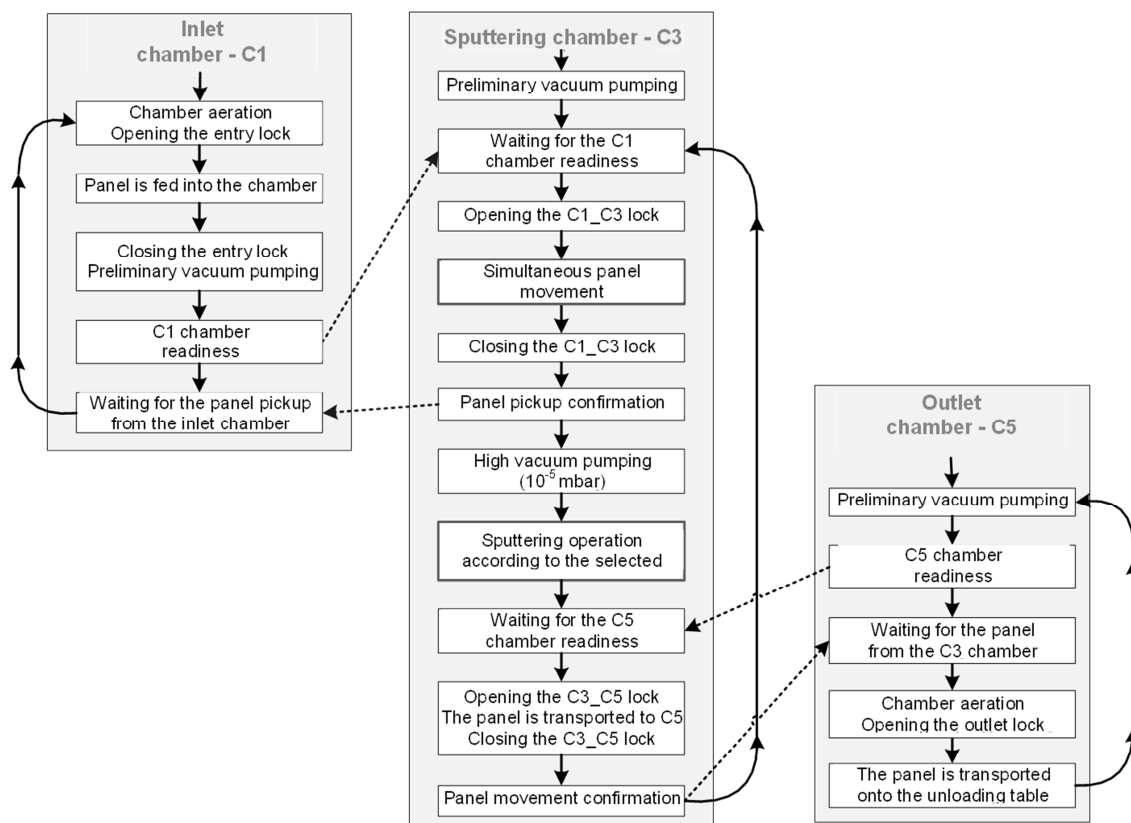


Fig. 6. A diagram of the vacuum chamber control algorithms in an automatic cycle

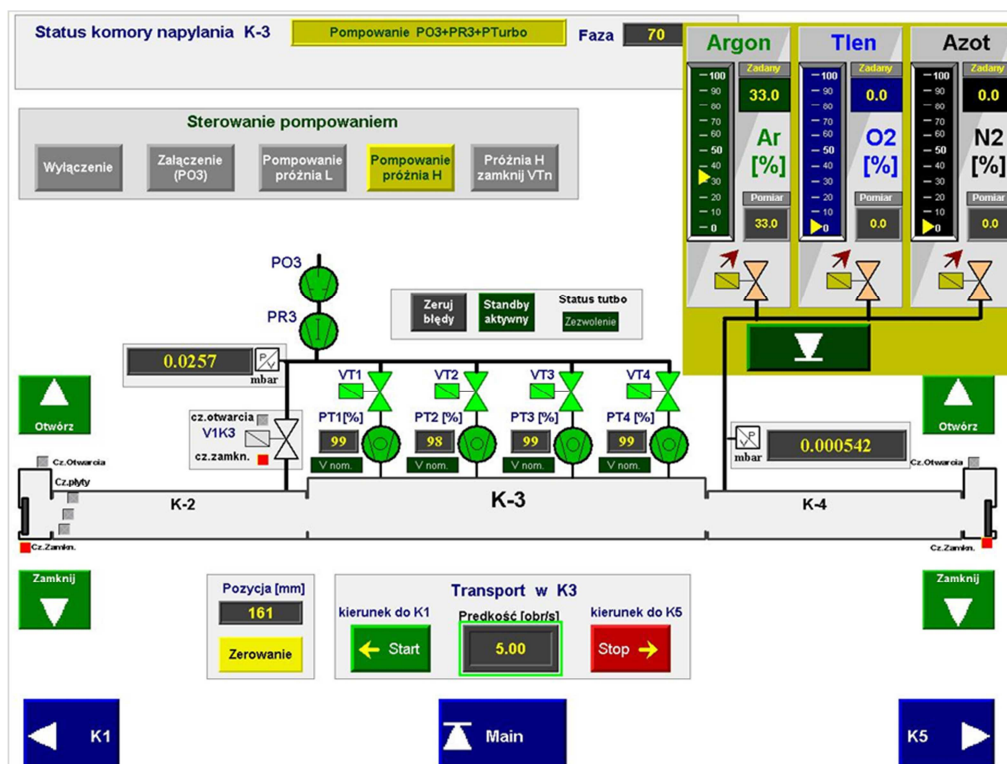


Fig. 7. Operator interface screen in manual sputtering chamber control mode

The machine operator interface software running on a touch screen PC enables the user to open a number of individual windows that display only those function buttons that are active at the given time. Graphical visualization of the line allows for simple and intuitive process line operation from the operator's level. Figure 7 shows a sample line visualization screen in manual sputtering chamber control mode.

5. CONCLUSIONS

A processing line was designed and built for industrial deposition of thin films on large-size glass panels. This thin film deposition line has been implemented at Z.P. Bohamet in Białe Błota near Bydgoszcz, one of the leading manufacturers of marine windows in the world. Considering the large number of small series of products manufactured according to specific orders placed by various ship owners, the implementation of a flow processing line for thin film deposition has been an economically justified investment.

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