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INNOVATIVE AUTOMATED ADHESIVE BONDING PROCESS IN THE WOOD INDUSTRY

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Abstract. *The glueing operation represents a very critical phase in the production processes typical of the wood industry, as it affects the products quality level and is a tiring and dangerous task for the operators. In this work, taking as a starting point the production process adopted in a small firm operating in the furniture sector, an optimization of the prefabrication operations has been carried out and an automated solution has been conceived for the execution of glueing on wood parts. Specific automated equipment has been developed able to carry out the clamping functions and the locking of components in desiccation phase. Materials loading/unloading operations are instead carried out by hand. To the theoretical development of the equipment follows the prototypal installation on which clamping mechanisms have been tested and optimized.*

Keywords. *Wood Industry, Automation, Adhesive Bonding*

1. Introduction

The production process adopted in the furniture and wood transformation industry may be summarized as a sequence of four main phases:

- *Machining of parts*: the parts to be used in the furniture fabrication are obtained from wooden planks through longitudinal cuts and profiling operations, in order to obtain elements having contoured shapes.
- *Prefabrication:* machined parts are bonded through glueing or mechanical joints and cut to measure in order to obtain elements ready to be assembled in the furniture.
- *Assembly:* the elements obtained in the preceding phase are bonded together, through glueing or mechanical joints.
- *Finishing:* sandpapering and painting of the furniture.

Process automation has been introduced from a long time in this sector, above all in the machining and the finishing phases. The execution of glueing operations in the prefabrication and in the assembly continues instead to be carried out primarily by hand. However, some examples of robotized glue deposition (Razban et al., 1995; Davies et al., 1996) can be found in literature, although representing exceptions not directly linked to the wood industry.

The manual execution of the glueing task introduces some problems in the manufacturing process (Bandel, 1984; Giordano, 1983; Marra, 1992; Pizzi, 1994; Tsoumis, 1991).

- It forces the operators to work constantly in presence of chemical compounds which sometimes may result dangerous for their health.
- In order to obtain a perfect adhesion between the frame and the table it is necessary that the glue is applied in the right quantity and in uniform manner on the contact surfaces. In fact, if an excessive quantity of glue is applied, during the clamping phase it escapes from the interface between the parts. The excess glue has to be removed before it begins to solidify, otherwise during the following phase of painting the surface will show irregularities that will require extensive reworks to be eliminated. On the contrary, if the glue is deposited in quantities smaller than necessary, at the end of the glueing cycle the parts will not stick perfectly each other and the whole cycle will have to be repeated. When the glue is applied by hand, the results of the glueing operation rely on the experience of the operator, with clear negative reflections on the average quality level of the product.
- The components to be bonded through adhesives usually are prepared on profiling machines in order to perfectly match each other. After this operation, the components are subject to deformation due to strain recovery in wood fibres. If the glueing operation follows immediately the profiling operation, this drawback can be easily overcome by the rigidity of the assemble, which may prevent the bending of the product. Due to production planning problems, in many cases the profiling operations are carried out on production lots of remarkable volumes: in these cases it may take some time, for the prepared parts, before undergoing the glueing operations and special expedients have to be used in order to recovery the deformations which in the mean time have taken place in the components. One such expedient is the resort to mechanical devices such as carpentry clamps which allow to maintain the parts joined till the glue has completely dried. The manual application of these clamps is time consuming and may therefore cause the drying operation to constitute the bottleneck of the whole production process. Furthermore, the manual locking of the clamps requires remarkable torque and is therefore very tiring for the operators.

- The necessity of an optimal drying of the glue in order to obtain a satisfactory quality product requires the resort to controlled environments not always available in firms of small-medium dimensions. Often in such contexts, to accelerate the completion of such phase, *do-it-yourself* solutions of doubtful effectiveness and surely of scarce efficiency are conceived, which sometimes may also be source of danger for the operators using them.

In order to solve such problems, two useful measures may be undertaken:

- an optimization of the process by a production planning point of view, in order to minimize the times between preparation and glueing operations therefore preventing or, at least, reducing the parts deformation;
- the resort to automation, in order to:
  - avoid the direct contact of the operators with the dangerous chemical compounds possibly present in the adhesives;
  - apply the right quantities of glue on the parts to be bonded;
  - reduce the times needed for the clamping;
  - relieve the operators of the tiring clamping tasks;
  - apply the right locking force on the clamps during the drying phase;
  - supply a controlled environment for the storage of the parts in optimal conditions during the critical glue drying phase, to obtain shorter drying times for the glue.

2. Automated bonding process in a wood working company

A case study involving a small company operating in the furniture sector is described in the following.

The furnitures are built assembling elements which are prepared in the company prefabrication department. These panels are composed of a table with frames of different shape applied on it by means of a glueing operation. Subsequently, such panels are cut to measure to obtain elements ready for final assembly.

2.1. Present manufacturing process

The production process used by the company may be summarized as follows:

- machining of parts, through:
  - raw materials (planks) withdrawal from warehouse;
  - profiling of parts on profiling machine;
  - storage of profiled parts in warehouse;
- prefabrication of elements, by means of:
  - glueing operation:
    - parts withdrawal (tables and frames) from warehouse;
    - glueing of frames on tables to obtain prefabricated panels;
    - desiccation of glue;
    - storage of panels in warehouse;
  - cutting operation:
    - panels withdrawal from warehouse;
    - cut of panels to measure;
    - storage of cut elements in warehouse;
- assembly of elements composing the furniture, obtained through:
  - elements withdrawal from warehouse;
  - bonding (through glueing and/or mechanical joining) of elements in the furniture;
  - desiccation of glue;
- finishing, consisting of:
  - sandpapering of surfaces;
  - painting;
  - storage of furniture in finished products warehouse.

As far as it concerns manufacturing facilities, the machining department of the company is equipped with high production, high technological level machines recently purchased. A modern painting plant can be found in the finishing department. Equipment and painting plant capacity is not yet fully exploited.

Some phases of the production cycle are entirely manual and a large part of the workforce is engaged in them. In particular these phases concern prefabrication and assembly processes.

From an analysis of the present production method it was found that the assembly process, for its nearly handicraft nature, is not suitable to be automated, not even in a partial measure, while the prefabrication process, in particular the frames glueing, characterized by a series of time consuming operations, could be automated by means of specific equipment. From a market research it was not possible to find automatic equipment dedicated to these operations neither it appeared suitable the employment in such operations of robotized flexible systems.

At present, the manual glueing operation is carried out by two operators in a station with six assembly workbenches and two warehouses for the components. The number of six workbenches was originally chosen in order to provide the operators with enough work in progress to allow for a complete desiccation of the glued parts without occupying excessive floor space, considering the large size of the workbench (more than two meters long) and the physical fatigue involved in the task.

The components to be joined in the prefabricated panel are organized in kits including table, frames and cylindrical fillets (Figure 1).

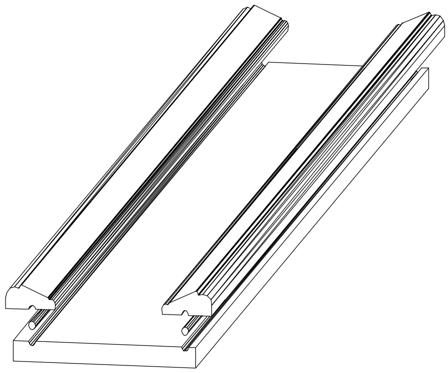

Figure 1. Manual assembly kit

The cylindrical fillets are not visible in the final assembly but they have the function of making easier the alignment operation of the frames on the table.

The frames and the tables, before the glueing operation, are prepared on the same profiling machine. This machine requires high set up times; therefore, production lots are rather large and production runs may last up to four or five weeks. During this long period of storage after profiling, the frame, given its particular geometric configuration, under the action of the residual tensions produced by the wood removal, is subjected to bending and warping. During glueing phase the frames applied on the table are straightened and aligned through the application of carpentry clamps which are locked in specified points following an orderly sequence. The first to be locked is the clamp placed at the center of the frame and then, alternatively, the ones on the left and the right towards the table extremity, in order to allow a gradual straightening of the frame. The straightening is also made easier by the insertion of the cylindrical fillet between the table and the frame, acting as guide for the latter. The clamps apply high forces (around 700 N) for the whole period of the desiccation of the glue, deforming irreparably after few manufacturing cycles and requiring therefore their frequent substitution. Furthermore, the clamps cause notches on the wood surface: for this reason at present direct contact between clamps and frame is avoided by interposing properly contoured wooden fixtures.

The tasks carried out by the operators in the glueing operation may be summarized as follows:

- kit withdrawal from warehouse;
- kit deposition on the first assembly workbench;
- manual application of glue on table and frames;
- positioning of two cylindrical fillets in table’s grooves;
- positioning of the two frames on the table;
- application of clamps on the table;
- locking of the clamps;
- repetition of previous tasks on the other five assembly workbenches;
- waiting for the desiccation time;
- unlocking of the clamps;
- storage of panels in warehouse.

Through a work study carried out on the present assembly method it was found that it takes to operators about:

- 20 minutes to complete all the assembly operations;
- 15 minutes to wait for the complete drying of the glue;
- 5 minutes for clamps unlocking and tables transfer to semi-finished products warehouse.

Though in theory these should be the actual working times, the production rate of the station results notably lower, due to a series of problems, first of all the operators fatigue provoked by the manual locking of the clamps. An average of 20-25 tables/day are in fact bonded on the station, and the inactive operator time amounts to around 20 minutes per cycle; however this time span is utilized by the workers to recover from the physical stress.

Keeping into account all the aforementioned problems, a study was undertaken in order to conceive an automated solution for the execution of glueing process.

2.2. The automated system

The guidelines followed in the development of the project were:

- to solve the problems in the present glueing station (reduction of the cycle times and elimination of the tiring phases of manual clamps locking);
- to exploit to the best the Company production resources with consequent increase in the production volumes;
- to obtain a uniform qualitative level of the glued components.

The main goals of the design phase were:

- to devise a semi-automatic pressing system able to:
    - relieve the operators of the clamps locking operation;
    - work in continuous manner eliminating the current downtimes in the glueing station;
    - allow for a significant increase of the glueing station production rate;
    - always guarantee the exact applied pressure on the frames;
    - automatically allow for the correct clamping sequence;
- to obtain a clamp able to:
    - withstand the stresses to which it is subjected without getting irreparably deformed after few production cycles;
    - apply the right clamping force without notching the frame surface;
    - match all the table-frame pairs present in production catalog.

The devised glueing cell is composed of the following parts (Figure 2):

- kit warehouses;
- glueing machine (figure 3) on which the glue is applied on parts to be bonded;
- preparing workbench, on which the parts to be bonded are coupled;
- clamping station, which carries out the locking-unlocking operations on the clamps on a pressing workbench;
- drying buffer – conveyor, in which the panels are stored in a controlled environment (in temperature and humidity) for a time sufficient for the glue drying;
- exit workbench;
- finished warehouses.

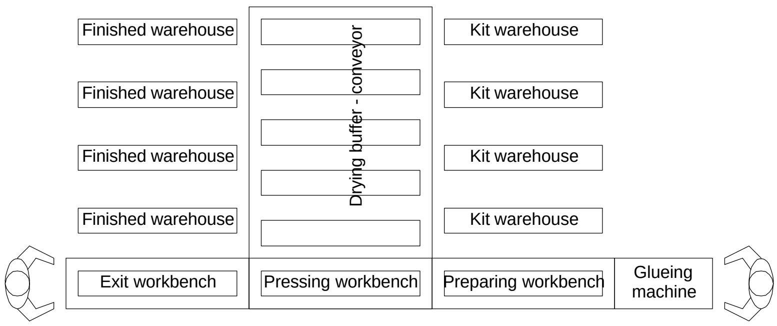

Figure 2. Layout of the proposed system

Figure 3. Glueing machine

The new automated process adopts proper metal frames to keep the panel clamped during the glue drying phase. Each panel needs ten couples of clamps to be pressed, and ten panels need to be contemporarily stored in the buffer in order to guarantee the necessary production rate. It was not possible to equip each clamp with an automatic device able to guarantee the necessary pressure on the table and its locking (for example: a pneumatic actuator), because a number of at least one hundred actuators would have been necessary, with a rather high cost and compressed air supplying problems. It was then conceived to distinguish the clamping and locking phases, by means of only one pressing system and a series of low cost self-locking clamps mounted on each frame.

Each clamping device (each one comprising two clamps) is composed of two vertical uprights, with square section, on which a horizontal crossbar may slide. Crossbar is pressed against the panel by a single pneumatic actuator (a total of ten actuators is required to press the ten couples of clamps on each frame) until it is in position to apply the required force. Once in position, two lateral toggles are released in order to hold the crossbar against the panel. The toggles, in fact, bear a timely shaped hole which allow the crossbar to slide along the uprights when they are in horizontal position, while in inclined position, due to the friction forces that are produced between the uprights external surfaces and the edges of the shaped hole, exert a force sufficient to lock the panel (Figure 4).

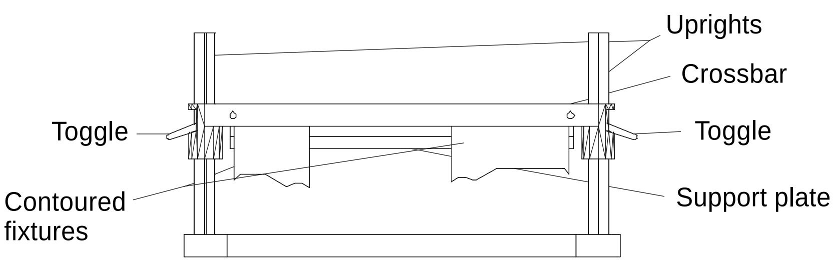

Figure 4. The locking system

Each crossbar is fitted with two contoured fixtures, matching the wooden frame profile, which, being made of a proper resin, allow to obtain a correct pressures distribution on the frame without notching it. The stems on which the patterns are mounted may be set sideways to adjust the system to different table-frame combinations.

The pressing system (Figure 5) is composed of a series of pneumatic cylinders mounted on a frame, which by pushing mobile bars transmit the motion to the clamps crossbars. The operation of the cylinders is planned in such manner that the clamps are locked respecting the above mentioned sequence.

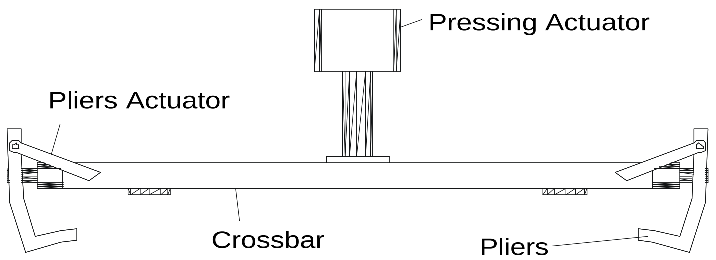

Figure 5. The pressing system

During the clamping cycle, in order to allow the slide of the mobile crossbar on the uprights, the toggles are held in horizontal position by two pliers fitted at the extremity of the crossbar itself (Figure 6.a). When the fixtures have reached the matching wooden frame and the proper pressure is applied, the pliers, operated by the actuators on the crossbar, release the toggles thus locking the clamp in position (Figure 6.b). At this stage the pneumatic actuators operate upwards the crossbar, which comes back to the starting position (Figure 6.c).

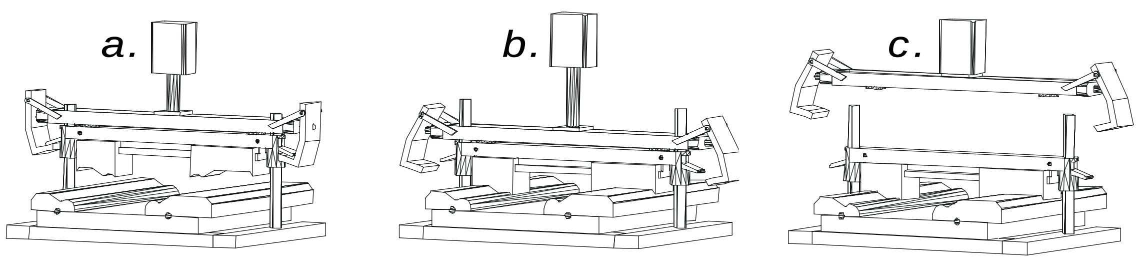

Figure 6. Pressing - locking sequence

The sequence of the phases in the glueing cell is the following:

- picking of a new kit (table, frames, fillets) from the kit warehouse and simultaneous transfer of the previous cycle finished panel from exit workbench to finished warehouse;
- introduction of the table in the station making it slide under the rolling glue distributor;
- positioning of the fillets in the proper table grooves on the preparation workbench;
- introduction of the frames in the station making them slide under the rolling glue distributor;
- transfer of the panel on the pressing workbench and simultaneous transfer of the previous cycle dried panel from the pressing workbench to the exit workbench;
- descent of the pressing system and clamps locking on the pressing workbench;
- transfer of the clamped panel on the buffer-conveyor and simultaneous transfer of an already dried panel on the pressing workbench;
- unlocking of the clamps on the pressing workbench for the already dried panel.

As far as the drying buffer architecture is concerned, in a first approach a solution with a vertical carousel (Zignoli, 1973) was investigated, because of the rational use of the available room it would have allowed, thanks to its limited dimensions on plan. In order to obtain a production rate of about one table in three minutes and to make the tables stay in the system for the time sufficient to the glue desiccation, it was found that at least ten tables had to be stored in the buffer. In order to help the deposition and the collection of the tables a possible solution was to bind the clamps to the chain of the transport system. However, a carousel height of around 5 meters would result, from the necessity to interpose a distance of at least one meter between a table and the following to avoid interference during motion. Therefore complex and expensive safety devices would have been required, making this solution unattractive. A horizontal carousel (Zignoli, 1973) was therefore chosen (Figure 7).

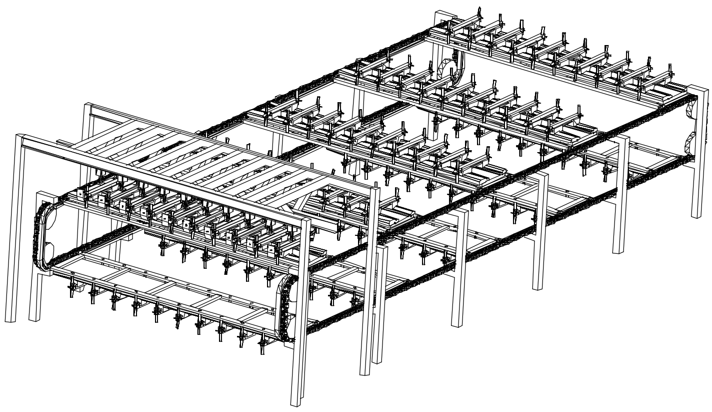

Figure 7. Solution with horizontal carousel

The elements characterizing this transport system are:

- n° 10 carts;
- n° 2 traction chains;
- n° 8 cogwheels for chains;
- n° 2 side guides.

3. Prototypes and experimentation

In order to verify the correct working of the locking system, some tests were carried out on a prototype clamping mechanism (figure 8) fitted with load cells, with the aim of verifying if the locking system was able to maintain the pressure on the frame after the pressing system was operated.

Figure 8. Prototypal installation

Results from the tests stated that when the pneumatic actuators were retracted the locking system was able to maintain only one third of the force initially supplied (1000 N) by the pressing system (Figure 9).

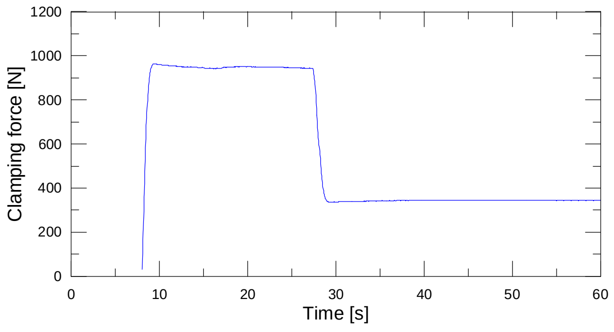

Figure 9. Locking force in the first solution

In a first transient phase, the clamping force rapidly rises up to the maximum value applied by the actuator. Until the actuator remains in position, this force value is maintained steadily, while it abruptly drops to the final value, guaranteed by the locking device, as soon as the actuator is retracted. In fact, it was observed that in the instant of actuator retraction the crossbar raised of about 2 mm due to the not optimised shape of the toggles holes which did not allow a proper friction on the uprights surface. The change of the rim geometry in the holes allowed a slight increase in the ability of the system in maintaining the locking force (Figure 10). Around one half of the initial locking force was therefore maintained by the system.

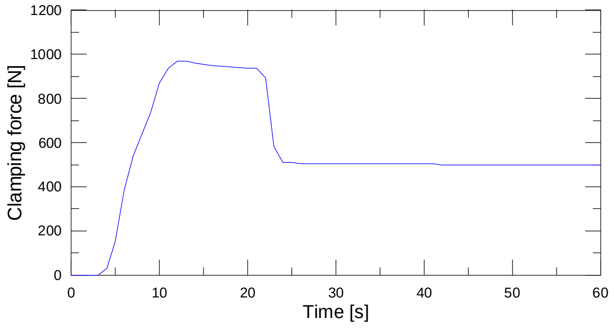

Figure 10. Locking force of the clamp after changing in the joining geometry

It was subsequently conceived that a reduction in the rigidity of the system would have further improved the clamp performance. The following tests, carried out interposing between the clamp and the load cell materials with remarkably smaller rigidity with respect to steel, such as plastics and polystyrene (Figure 11), confirmed this hypothesis.

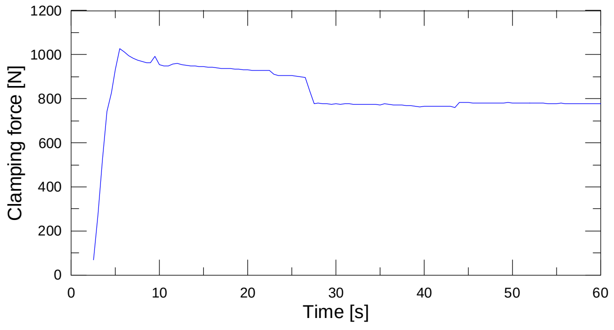

Figure 11. Locking force of the clamp with reduced rigidity material interposition between clamp and load cell

The following step was therefore to identify a solution to reduce the rigidity of the clamp. The solution found was to interpose some Belleville washers along the lines of application of the forces. The choice fell on this type of spring because they maintain a fairly constant force as their strain changes. The springs were interposed between the patterns support plate and the inferior surface of the crossbar (Figure 12).

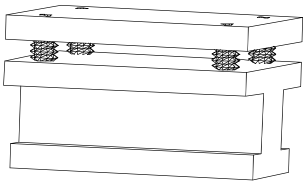

Figure 12. Interposition of elastic devices between pattern support plate and crossbar

Figure 13 depicts the experimental trend of locking force with the interposition of the springs. It clearly results that the system is able, in this configuration, to maintain about the 90% of the initial locking force.

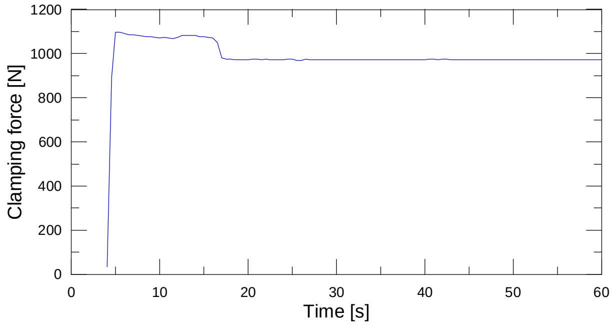

Figure 13. Locking force of the clamp after changing in the joining geometry, with interposition of Belleville washers

Such tests therefore enabled to demonstrate the feasibility of the most critical component of the automated assembly system proposed.

4. Conclusions

An automated solution for the execution of adhesive bonding in the wood industry has been described.

The automated solution represents an answer to the problems of the manual glueing process which at present is employed in the production of panels for furnitures manufacturing. In fact it is a relatively economic solution and allows for:

- the reduction of the cycle times;
- the elimination of tiring phases of manual clamps locking;
- the best exploitation of the Company production resources (with consequent possible increase in the production volumes);
- the matching all the couples table-frame present in production catalogue;
- the obtaining of a uniform qualitative level of the glueing process, thanks to:
    - the optimal conditions of glue drying;
    - the uniform drying times;
    - the optimal clamping pressure distribution, which also guarantees the absence of notching on frames;
    - the optimal quantities of glue applied by the glueing machine.

The most critical elements of the automatic assembly machine have been also tested in prototypal form giving satisfying results.

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