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A Portable Light System for Saffron Harvesting

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Abstract - The system described here is conceived as a shoulder portable device for saffron flowers detaching and collecting. The system is a portable light machine, carried by the human operator on his back during the harvesting phase of the saffron production. The main parts of the system are two: the first one is a gripper designed to detach the flower containing three stigmas, which are the costly final product; the second one is aimed to collect the detached flower through a vacuum collector. In this paper, the operating principles of detaching and collecting devices are described: a model of the gripper is written and compared to the experimental laboratory tests. The model is also used to investigate the system operating principle sensitivity to the variation of some physical characteristics of the gripper. Experimental tests on field are also described to know on field performances of the system.

Keywords—mechanical harvesting; gripper; flower detaching.

I. INTRODUCTION

The new century has given great importance to biological sector in farming. Until the last years of Twentieth Century, the biological sector has not greatly developed and appealed to a niche market. With the beginning of the new century a period of rapid development is being imposed on the market, with also the EU support. Currently, organic agriculture is a very large and vital activity in view of agricultural production.

In this framework, Italy is one of the most "biologic" countries in Europe with about 50000 biologic farms compared to 150000 in UE, and 1,5 million of hectares worked biologically respect to 4,5 millions in UE (www.coldiretti.it). Furthermore, in Italy there is about the 30% of the UE biologic farms and the 25% of the EU worked surface. About 1,5 GEuro is the annual value of the biologic market in Italy, with about 25 Euro spent per capita in mean, as shown in Figure 1.

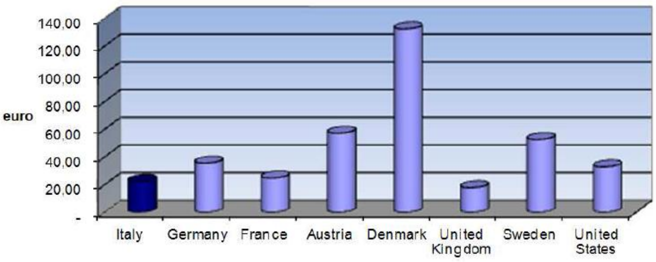

Fig. 1. *Per capita buy in different countries(figure caption)*

The saffron spice is certainty a biologic product and, in the graph in Figure 2 is put on the bill of the 8% of the condiments. The saffron production values are represented in the graphs of Figure 3: in the face of a world production of one hundred and seventy tons of dried saffron, Europe produces only seven tons, whereof six quintals come from Italy, and three of them from Sardinia, which sells thus a quantity of saffron significantly higher than that produced in the other Italian regions.

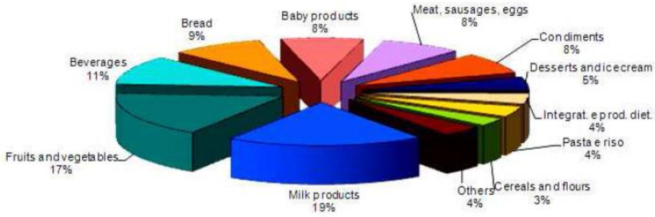

Fig. 2. *The biologic food market percentage for different products*

Actually, the total amount of saffron sold in Italy is more than eighteen tons, and only six are produced in Italy. Thus, the vast amount of saffron sold in Europe comes from abroad.

The graph in figure 3 shows the production levels in world, Europe, Italy and Sardinia. It is possible to see that almost all saffron is currently produced out of Europe: the labor cost can be very different and very lower out of Europe, and the saffron, nowadays harvested and separated by hand, requests many labor hours for on kilogram of spice. It is also interesting to note that, despite the fact that saffron is produced mostly outside of Europe, European companies manage almost the entire market for the saffron marketing and distribution.

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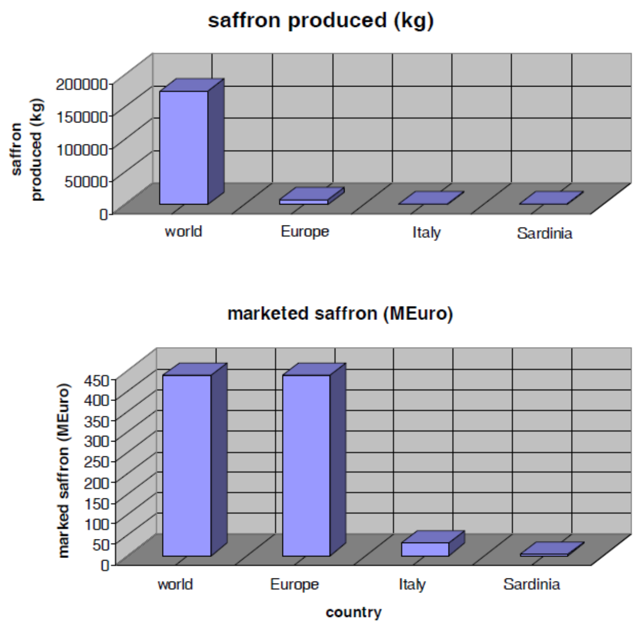

Despite the strong growth of the biologic sector, the saffron spice production is actually marginal because of the high cost of production phases, especially for the harvesting phase. [1]

In the graph in Figure 4 the working time, directly linked to the costs, is given for different phases in saffron production. The heaviest phases are harvesting and separation, which must be distinguished from one another. Separation is the longest phase in the saffron spice production, but it is less heavy than harvesting: separation is performed at home by operators seating at a table and in company with other people, being a pleasant social time as well; harvesting, however, takes place in the early morning under the threat of possible rain that would destroy the flowers; in fact, rain occurs frequently in the flowering season, that is the autumn. For harvesting an efficient and physically valid team is required, because flowering occurs over a few weeks in an entire region, engaging simultaneously all available operators.

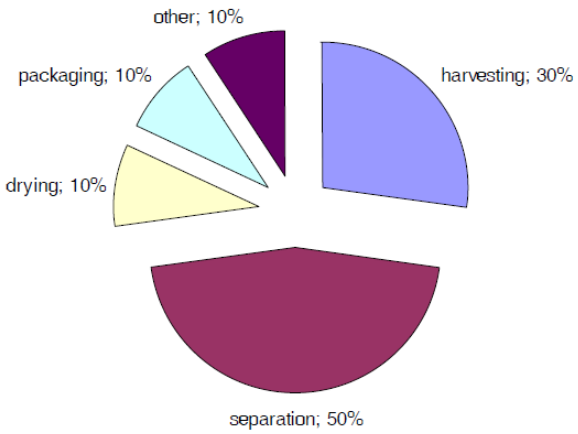

Fig. 4. *Time for different saffron production phases*

In this framework, the saffron harvesting phase mechanization is a proposal to make the cultivation of saffron a significant sector of biological agriculture. A mechanical system, for handling delicate and soft objects such as fruits and agricultural products in general, requires careful development of sturdy and dexterous grippers, using also non conventional working principle. The use of different techniques for picking delicate and soft objects, like fruits, is described in [2-4].

Given the necessity of grasping objects like agricultural products, particular versatility characteristics are required. Grasping non-uniform objects in size and shape, and not located in known positions, imposes to the grippers particular characteristics such as versatility, self cantering approach strategies, gentle and safe grip. An example of this topic is given in [3], where a pneumatically driven soft hand for delicate fruit harvesting has been developed; the hand is equipped with delicate flexible fingers made of elastomer [5-8].

A mechanization of the harvesting phase of saffron flowers will allow a drop in costs and a growth of areas dedicated to saffron culture. In addition, the mechanisation means modernisation and increased attractiveness of the activity for workers, nowadays suffering during the very tiring harvesting on field, and then it is a resource that can boost local economic development.

The on field activity for high cost agricultural products involves different research aspects and applied mechanical topics, customized to the specific application.

The design of mechanical system, for handling delicate and soft objects such as fruits and agricultural products in general, is an outstanding topic for applied robotics. This matter requires to address particular topics such as development of robust and dexterous grippers, using also non conventional working principle. The yield is very high in the case of flowers to produce spices like Saffron.

II. THE GRIPPER TO DETACH THE SAFFRON FLOWER

The mechanical system described in this paper is a shoulder portable device with two main parts, the first one for detaching the corolla from the stem, and the second one for collecting the flower. The portable device for harvesting Crocus Sativus in the field is represented in figure 5. This device is a lightweight system that make it possible to perform an efficient harvesting operation in the field.

In particular, in figure 5 it is possible to see the handle (1), equipped with the pneumatic valve manually operated to perform the gripper pneumatic actuation; the body (2) supporting the electrical motor equipped with the fan for vacuum generation to inhale the detached flower; the suspender (3), allowing to perform the harvesting without bending; the integrated pneumatic pipe to supply the pneumatic actuator assembled in the gripper body; the vacuum tube (6) to collect the flowers; the elastic link (7) to the device body of the gripper body (8), with the two fingers (9), to detach the saffron flowers. This link has a hinge elastically winded up around a horizontal axis to allow rapid rotation of the gripper body when the lower is detached; this movement allows to approach the flower the vacuum system inlet.

The gripper is a one degree of freedom pneumatically actuated device. The actuation, pneumatically powered, is quite suitable for operations in agricultural fields. A successful detaching phase of the saffron flower harvesting process strongly depends on the system dynamics.

Fig. 5. *The portable device for detaching and harvesting Crocus Sativus flowers on fields*

In Figure 6 it is possible to see an internal view of the gripper. It can be seen the pneumatic line (1) to supply the cylinder, the aluminium alloy body (2), the mini pneumatic cylinder (3) having a stroke of 25mm and a bore diameter of 16mm, acting with its rod on a translating crossbar (4). The crossbar push two cylindrical bodies (5), rigidly linked to the fingers; these bodies translate and rotate in two bushings (6), with a helicoidal guide (7) working as a cam linked to the cylinders to obtain an helicoidally motion of the fingers (8), that are linked to the cylinders. The fingers detach the flower, realising a reciprocal rototranslation, avoiding the sliding motion between fingers. The cylinder rod moves the two fingers (5) pushing the crossbar (4). Between fingers (5) and crossbar (4) there is a relative rotation, which is allowed by a thrust bearing disk-shaped. This disk, working as a plate type dry-disk clutch, is assembled axially to the cylinder bodies (5).

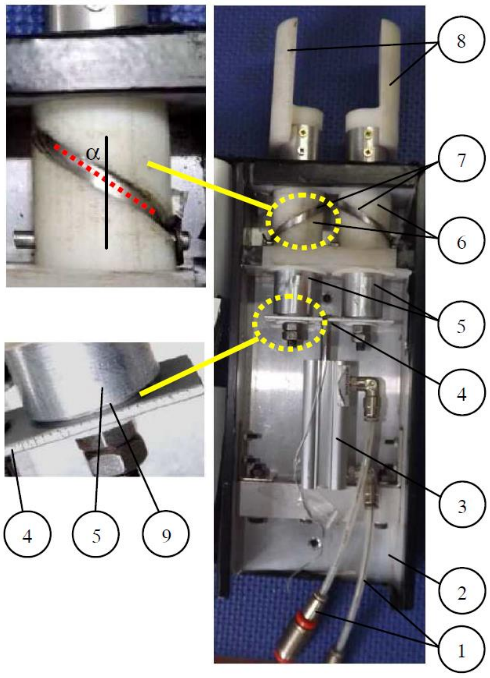

Fig. 6. *Internal view of the gripper*

The gripper is sensorized, where the measured variables are the two pressures in the cylinder chambers and the position of the cylinder rod, driving the fingers motion. The pressure transducers has a range of ± 1.46x106 Pa with a sensitivity of 6.89x103 Pa/mV; the rod position is detected by a wire displacement sensor having a 140mm range and a gain of 78.724 mV/mm. The transducers signals are processed and stored by an acquisition board (Compact DAQ) National Instruments mod. NI 9219 with a resolution of 24 Bit and 100S/s/ch.

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III. THE DYNAMIC BEHAVIOUR OF THE GRIPPER

The dynamic of the gripper movement strongly affects the success of detaching phase in the harvesting Saffron flower process. The sequence of fingers movement and bending rotation of the entire gripper body, around the elastically loaded horizontal hinge, must have a given time sequence. Since the bending movement must take place when the fingers movement is completed, sufficient velocity of the cylinder-fingers group is necessary to guarantee an adequate strong shock at the end of cylinder stroke.

The graphs (a) in Figure 7 show the experimental pressure trends in anterior and posterior chambers for a supply pressure of 4,0 bar relative during three repeated cylinder cycles. The pressure, when discharged to the ambient, reaches quickly the environment pressure level; this trend is also favoured by the decreasing volume in the anterior chamber due to the piston movement. On the other hand, when the pressure increases in the cylinder chamber, the volume increases because of the piston motion and the pressure trend is more gradual.

Graphs in Figure 7(b) show the pressure trend in the first time interval, immediately after valve commutation. The increasing pressure is in the posterior chamber, the other is in the anterior one: when the cylinder rod is getting out, the fingers approach to the flower steam. The pressure trend in Figure 7(b) illustrates the initial phase of the gripper manoeuvre, which starts with the opened fingers corresponding to a cylinder rod in retracted position. Pressure in the posterior chamber starts from the environment value, while pressure in the anterior one decreases from the maximum value.

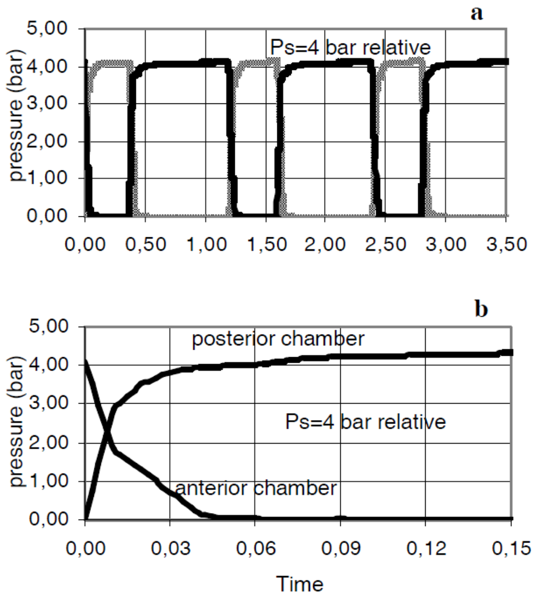

Fig. 7. *Pressure trend in the cylinder chambers for a supply pressure of 4,0 bar relative*

Figure 8a shows the correlation between the pressure values in the cylinder chambers and the position of the crossbar, linked to the cylinder rod. The curves, referring to 1,5 and 4,0 bar relative values of pressure supply, show a rapid movement of the cylinder piston driving the fingers of the gripper. The cylinder piston velocities for the different supply pressures are reported in Figure 8b. The velocity of the cylinder rod is rigidly linked to the velocity of the fingers in their helicoidally trajectories.

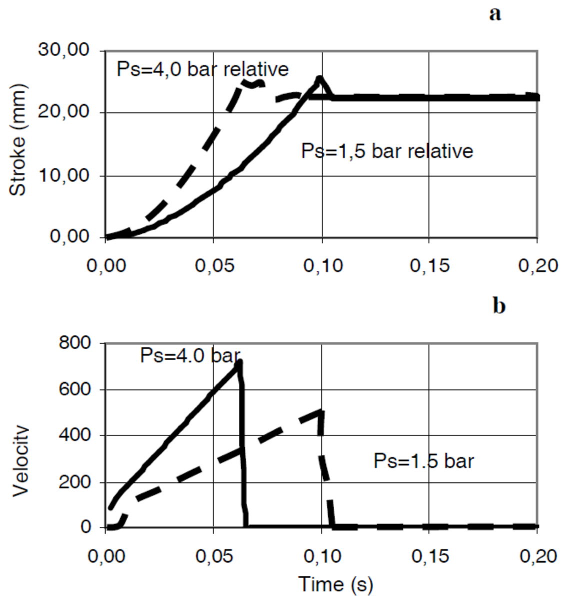

Fig. 8. *Stroke and velocity trend of the cylinder rod for a supply pressure of 1,5 and 4,0 bar relative*

The graphs in Figure 8a show a short time to complete the entire stroke for both the considered supply pressures: the stroke is completed in about 6/100 and 10/100 seconds respectively, for the higher and the lower supply pressure. Observing the end of the outstroke displacement, it is possible to find an overshoot displacement due to the elastic deformations, the inertia effect and the shock of the moving parts at the end of the stroke. The velocity is represented in the graphs of Figure 8b for the same supply pressure above considered. The curves also shows the influence of the supply pressure level: for a supply pressure of 1.5 bar relative, the velocity reaches the maximum value of 0.45 m/s in 0.10 seconds corresponding to an average acceleration of 4.5 m/s^2. For a supply pressure of 4 bar relative, the maximum velocity value is 0.65 m/s, reached in 0.06 seconds, and then corresponding to an average acceleration of about 10 m/s^2.

IV. THE GRIPPER DYNAMIC MODEL

A dynamic model of the moving system made by the cylinder rod and fingers is written to investigate the gripper dynamic behaviour and the influence of geometrical and physical parameters on it.

The variable representing the gripper behaviour is the position of the rod, rigidly linked to the fingers, which have a combined counter rotating and translating motion: only one degree of freedom is performed, as represented in Figure 6: An helical constraint is set for each finger with two pins per finger, diametrically opposite, engaging in a helical guides linked to the frame.

The pneumatic cylinder moves the crossbar that pushes both fingers that can rotate respect to the crossbar because of a plate type dry-disk clutch.

Through the free body diagram for one finger, the cross bar and the piston in the pneumatic actuator shown in Figure 9, it is possible to write the dynamic motion equations of the system [9, 10], taking into account the helical constraint, the friction Coulomb's model and the moment transmitted by the plate type dry-disk clutch [11, 12]:

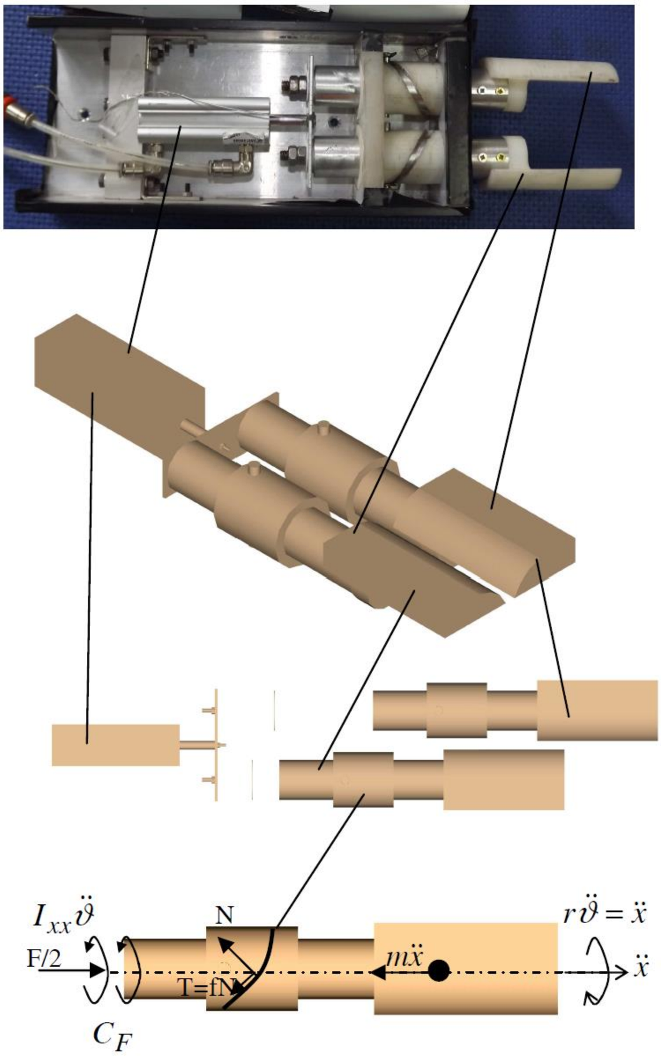

Fig. 9. *The moving parts in the gripper and the free body diagram of a finger*

The equilibrium equations for the fingers and the cylinder moving parts are:

$$F - 4N(\cos\alpha + f\sin\alpha) - m\ddot{x} = 0 \quad (1)$$

$$-Ff_F R_m + 4rN(\sin\alpha - f\cos\alpha) - \frac{I_{xx}}{r\tan\alpha}\ddot{x} = 0 \quad (2)$$

$$-F + P_1A_1 - P_2A_2 - F_a - m_S\ddot{x} = 0 \quad (3)$$

The first two equations describe respectively the translational and the rotational equilibrium of the finger, while the third one expresses the translational equilibrium of the piston-rod group. In these equations, the positive terms contribute to the acceleration, while the negative ones are resistant terms.

The model will be used to represent the outstroking phase of the pneumatic cylinder that corresponds to the fingers approaching motion to the flower stem. The pressure trend P1=P1(t) and P2=P2(t), experimentally measured and referred in Figure 7, are model inputs. The friction force Fa is a function of P1, P2 and piston velocity. In this specific case, Fa is manly dependent on P1 and P2, and it was defined experimentally [13-15].

Solving the equation system above gives the acceleration $\ddot{x}$ and then the displacement by integration. The detaching flower manoeuvre starts with the cylinder rod in retracted position.

In Figure 10 the displacement of the cylinder rod is illustrated for a supply pressure of 4,0 bar relative. The two curves represent the experimental and the modelled trends, both fitted by a second order polynomial function. The fitting functions of the experimental and the modelled trend are respectively:

$p = 5996t^2 + 45{,}268t + 0{,}1082$

for rod position experimental curve;

$p = 4846{,}8t^2 + 103{,}52t - 0{,}3607$

for rod position modelled curve;

where t is time in (s) and p is the rod position in (mm) starting from the retracted position during the stroke.

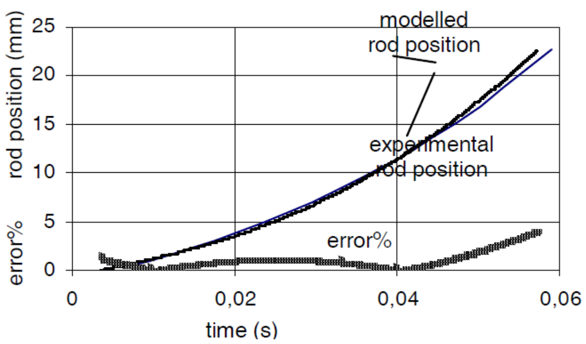

Fig. 10. *The rod position during the detaching phase and the error% between modelled and measured position referred to the cylinder stroke (22,5mm).*

The rod velocity trend experimentally measured is represented in figure 11

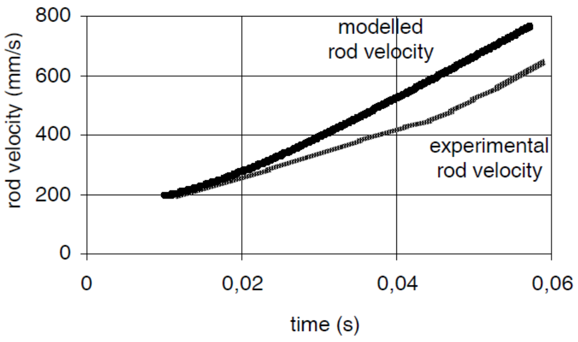

Fig. 11. *The rod velocity during the detaching phase: modelled and measured trends.*

V. CONCLUSIONS

The system to detach and collect saffron flowers was characterised by the experimental identification of the working parameters for a dynamic fast enough to perform an efficient detaching and harvesting strategy. The model proposed for the dynamic of the pneumatic cylinder-fingers assembly describe the displacement in well agreement with the experiments. Also the velocity was measured and modelled. Also for the velocity a satisfactory model behaviour was found. In future work the model will be used to maximize the gripper dynamic characteristics varying the geometrical and mechanical characteristics.

VI. NOMENCLATURE

variable	***description***
$F/2$	*force transmitted by the rod to the cross bar*
α	*helical angle*
f	*friction coefficient between the pins and the helical guide*
m	*mass of a complete finger*
f_F	*friction coefficient on the plate type dry-disk clutch*
R_m	*medium radius of the plate type dry-disk clutch*
r	*helical radius*
N	*normal force between pin and helical guide*
I_{xx}	*moment of inertia of a complete finger*
$\ddot{x}$	*axial acceleration*
P_1	*posterior cylinder chamber pressure*
P_2	*anterior cylinder chamber pressure*
A_1	*piston area in the posterior cylinder chamber*
A_2	*piston area in the posterior cylinder chamber*
F_a	*cylinder friction force*
m_s	*mass of the rod and piston group*

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