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A novel gripper for limp materials based on lateral Coanda ejectors

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ABSTRACT

Limp materials like textiles, leather, porous tissues, meat and fish fillets do represent challenges in automation. A universal gripping principle that is usable for all these materials is not known. This paper describes a new gripping principle based on a novel Coanda effect ejector meeting these challenges. This ejector allows the construction of a slim, plate-shaped vacuum gripper with multiple independent suction heads. Each suction head is powered by a newly patented lateral Coanda ejector that ensures gripping power on all soft or porous materials. The paper presents results of investigations on important parameters of the Coanda effect gripper.

1. Background

Automatic handling of limp materials is still a challenge. For many industries this means that operations where handling of textiles and leather is needed have been moved to low-cost countries. Certain types of industry using these processes still keep up production in high cost countries for other reasons, but are looking for all kinds of solutions to reduce cost in textile handling. One such industry is the furniture industry where handling of textiles and leather now represent the lager part of the cost on their production lines. Due to the large variation of materials used for furniture the requirements for any automatic handling systems are complex. For efficient handling a universal gripping technique is needed to enable robots to grip a wide variety of materials. After more than three decades of robotic development there are still no universal gripper solutions available for these materials. Seliger et al. [1,2] has done an analysis of the performance of different gripping methods. Dougeri and Fahantidis have demonstrated a soft finger gripper that will grip limp materials [3]. But this method pinches materials, it does not preserve shape, and it leaves crease marks on leather. A radial outflow gripper described by Erzincanli et al. [4] will handle low permeability materials. But it is unsuitable for porous materials like normal textiles.

Based on this analysis one can conclude that it is possible to find a gripper that will most probably be suitable for any specific material in a given condition. But this gripper might not be suitable for other limp materials that should be handled in the same automation setup.

2. Requirements and known solutions for limp materials gripping

The requirements for universal gripping are grouped in three categories related to surface, shape and structure. For leather and similar low-/non-permeable materials suction gripping performs well. But this method does not function on porous materials. Also uneven and rough leather will pose problems for suction gripping. The needle based and freeze grippers make unwanted traces of gripping of the surface of leather and other smooth materials. But they are well suited for porous textiles and other soft materials. Clamp gripping is less suitable since it pinches or crumbles the material, and it cannot maintain shape unless many clamps are applied along the object's edge. Stacking and de-stacking is not easy to perform with clamp gripping.

3. The Coanda effect gripping method

3.1. High volume flow gripping

The analysis above shows that for gripping by clamping, needles or freezing for gripping action there is no possibility to avoid the potential surface marks of the method. These methods do therefore not have any potential for development into more universal use.

The suction method does have a possibility for wider application. But the standard vacuum systems used for suction grippers are designed for large underpressure and small volume flows. They do not work on porous materials. A possibility is to use a vacuum generator similar to domestic vacuum cleaners to generate a large airflow. But then large tubes are needed from the suction cup to the vacuum generator. In addition gripping of large textile sheets requires several suction cups. If one of these suction cups looses contact with the material to pick up it will act as a "short circuit" that leads to loss of underpressure at all the other suction cups. The use of automatic cut-off valves for un-used cups can resolve this problem, but they lead to a more bulky system.

3.2. The Coanda ejector as vacuum generator

This analysis shows need for a device that can generate moderate underpressure and large airflow locally. Such devices exist in the form of Coanda ejectors.

The basic flow phenomenon is the Coanda effect flow redirection as illustrated in Fig. 1. Pressurized primary air is supplied via the

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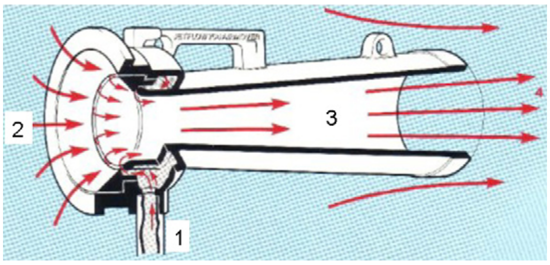

Fig. 1. Coanda ejector principle [5].

input channel (1) to an annular nozzle. The air-stream flows through this nozzle at high speed and adheres to the convergent nozzle wall, enters the narrowest section called the throat and continues along the walls of the diffuser (3). The primary air-stream interacts with the surrounding air in the inlet area and drags a secondary air-stream into the ejector. These streams mix all along the length of the diffuser. Ameri and Dybbs [6,7] have done a detailed flow analysis for cylindrical Coanda ejectors and have presented a method of calculation for the ejector's flow field. Their modelling shows that it can have a ratio of secondary to primary flow in the order of 10. It makes the Coanda ejector a good candidate for suction gripping of porous materials. It is easy to generate enough lifting force for textiles from a Coanda ejector.

4. The planar Coanda ejector

4.1. Planar design of a Coanda ejector

An array of cylindrical Coanda ejectors could be used for picking up plies of textile or similar materials. The only drawback of this design is its size. Textile parts are often stored in shelves. To save storage volume the space above the material in a full shelf should be as small as possible. For this reason the gripper based on cylindrical Coanda ejectors would be too big.

The needs for a slim gripper lie behind the idea of a planar Coanda ejector as shown in Figs. 2 and 3. This ejector uses the axial cross-section area of an ordinary Coanda ejector as the cross-section of the vertical side walls in a rectangular channel. The channel is limited on top and bottom by plain plates.

4.2. Determining diffuser length

From the velocity profiles of large cylindrical ejectors presented by Ameri [5] it was found that the thickness of the high-speed primary flow along the walls grows with an angle of approximately 12°. This growth is due to turbulent mixing with the induced secondary flow. The initial thickness of the high-speed flow is equal to the width of the injection nozzle, normally in the range 0.1–0.5 mm. From the throat it grows with approximately 12 mm per 100 mm diffuser length. For best suction performance the high speed stream on each wall of the planar ejector should meet. Thus it was concluded that the diffuser length should be at least eight times

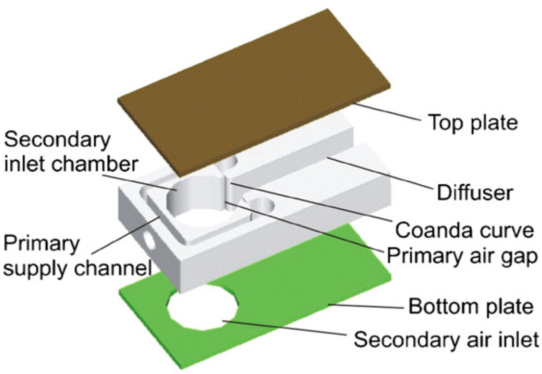

Fig. 2. Planar Coanda ejector CAD model.

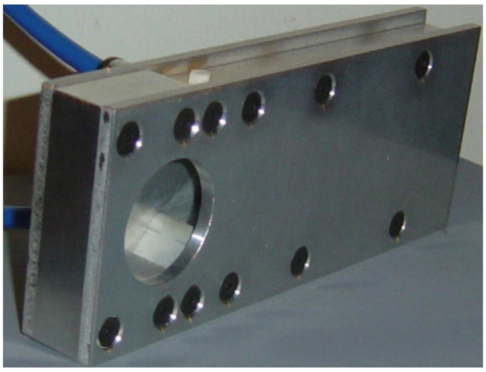

Fig. 3. Planar Coanda ejector.

the throat width. To test this assumption a test ejector with the same throat area as the reference ejector was built. It had constant diffuser diameter, the diffuser length could be varied from 40 mm upwards.

In the experiment this ejector was operated with blocked secondary inlet, and the obtainable underpressure was measured. The underpressure effectiveness shown in Fig. 6 is measured as the ratio between primary flow and obtained underpressure. The efficiency is highest in the length range 130–190 mm. Efficiency drops at lengths below 130 mm. It is also worth noting that the efficiency drops for lengths above 190 mm. This is probably due to increased friction loss in a long diffuser.

The prototype planar Coanda ejector shown in Fig. 3 was built with a distance (height) between bottom and top plates of 20 mm and adjustable throat width. Based on the analysis referred to above diffuser length 150 mm was chosen. Its performance was then compared to that of a standard Coanda ejector shown in Fig. 4.

5. The test procedure

No study of Coanda ejectors with partially restricted secondary airflow has been reported. The model presented by Ameri [5] cannot be used since it assumes unrestricted flow into the secondary air inlet. Simple models based on conservation of momentum in the flow fails dramatically because of the direction change of the flow vector. For this reason it was decided to proceed with a purely empirical test procedure to determine the performance of the ejectors. The main dimensions of the tested ejectors are given in Table 1.

The concept for testing of the planar Coanda ejector was to observe the holding force on different materials as function of the pressure and flow of the primary air. The measurements were then compared to the force obtained from the reference ejector.

Pieces of test material of suitable size were glued to a circular test frame. It has an inner opening larger than the secondary air inlet opening of the ejector. The frame was fixed to an arm with a pivot axis in the plane of the secondary air inlet. By alignment of this pivot axis it was assured that the test material had contact with the rim of the air inlet all around. Fig. 5 shows the test stand. Table 2 lists the measuring equipment used and Table 3

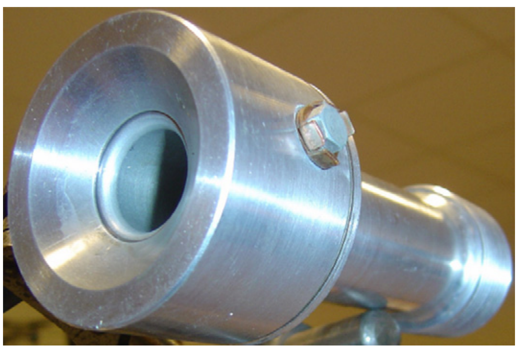

Fig. 4. Cylindrical reference ejector.

Table 1
Main dimensions of tested Coanda ejectors

	Type 1, Standard ejector	Type 2, Length test ejector	Type 3, Planar ejector
Throat size (mm)	∅20	∅20	20 × 20
Throat area (mm^2)	314	314	400
Exit Area (mm^2)	625	314	400
Primary gap (mm)	0.3	0.16	0.3
Gap length (mm)	79.2	75.4	2 × 20
Gap area (mm^2)	23.8	12.1	12
Coanda rad. (mm)	2.5	2	5
Dist. gap-exit (mm)	131	40–220	150
Air inlet area (mm^2)	1590	680	1256

summarises important test materials' properties. The transverse flow resistance was measured in a test chamber where airflow through known area and pressure drop was measured. For leather the airflow was too low to give reasonable resistance values.

A steel wire connects the frame to a carriage mounted force gauge. With the ejector operating the force gauge was moved to create a pulling force on the frame. The force exerted when the frame pivoted away from the ejector gives the maximum holding force for a given operating condition. This enables calculation of the underpressure using the ratio of force over inlet area.

6. Test series

6.1. Testing for optimal diffuser length

To determine optimal diffuser length a Coanda ejector with variable length cylindrical diffuser was produced with main dimensions shown in Table 1. As measure for effectiveness the obtained underpressure as function of primary mass flow was used. Leather was used as test material. Its very low permeability will demonstrate the largest obtainable underpressure for each flow level and diffuser length. The result of the test is shown in Fig. 6.

6.2. Comparative test of type 1 and type 3 ejectors

This test series compares the performance of a standard cylindrical Coanda ejector and the new planar version.

In this test the obtained underpressure was determined for four different materials. Smooth leather establishes the level of maximum underpressure that is obtainable. Figs. 7 and 8 show the measured performance. The new planar ejector shows better performance in terms of underpressure as function of primary flow. But since it has a smaller primary nozzle area it requires higher input pressure for a given underpressure requirement.

6.3. Test of single sided planar ejector

During the testing the idea appeared to check what happens if one of the primary streams of a planar ejector is blocked. A test setup was prepared where one of the nozzles in the type 3 ejector was blocked. In addition a moveable wall was placed in the diffuser. Tests were performed with varying diffuser channel widths. Fig. 9 shows the results of this series. The interesting observation here is that the performance is even better than for the type 3 ejector in terms of underpressure as function of primary flow. The channel width has opposite effect on leather and high porosity materials. For best performance on leather the channel should be quite narrow. For high porosity materials the opposite is the case. The tests show that height over width ratio of 2 is the best compromise for universal use.

In none of the tests were marks from the suction head observed on the test objects after release from the grip. This is particularly important for leather handling.

7. Planar multi-head suction gripper

The single sided planar Coanda ejector is particularly interesting as an element of a multi-head suction gripper. In a planar design it is easy to build arrays of ejectors with common supply. The gripper size and ejector placement pattern can be suited to the

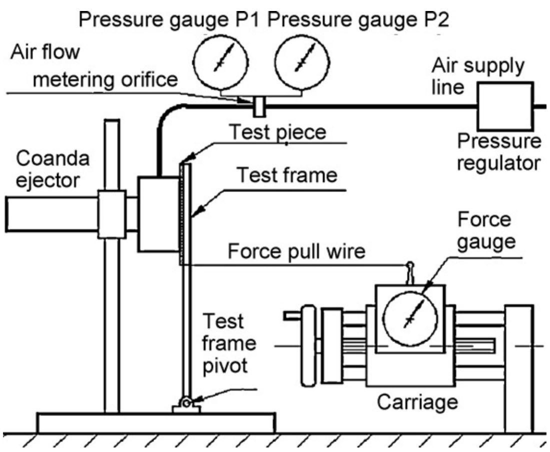

Fig. 5. Sketch of test stand for Coanda ejector effectiveness tests.

Table 2
Summary of measurement equipment used

Orifice flow meter	Tube diameter	16 mm
	Orifice diameter	7.5 mm
Pressure gauge	Range	0–1 kp/cm^2
	Accuracy	0.6% f.s.
Force gauge	Range	0–350 g
	Accuracy	1% f.s.

Table 3
Properties of test materials

Material	Thickness (mm)	Density (g/dm^2)	Transverse flow resistance, ζ
Leather, smooth	1.3	6.4	Very high
Wool/polyamide	0.5	3.3	2110
Knitted cotton	0.4	1.6	313

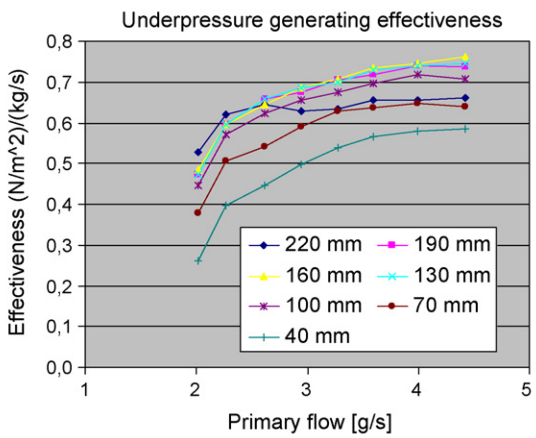

Fig. 6. Underpressure generating effectiveness as function of diffuser length for Coanda ejector type 2.

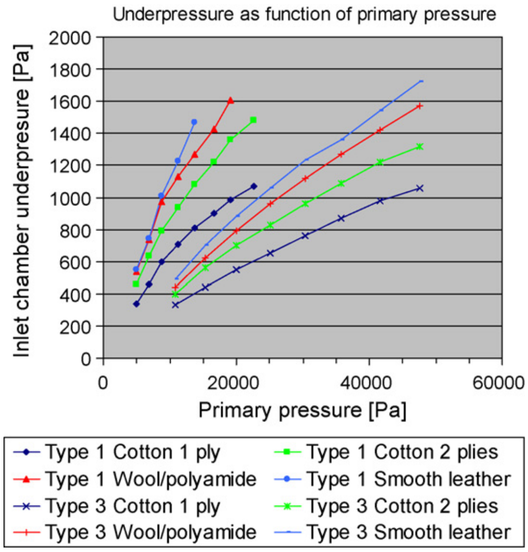

Fig. 7. Underpressure as function of primary pressure for textile and leather specimens, ejectors types 1 and 3.

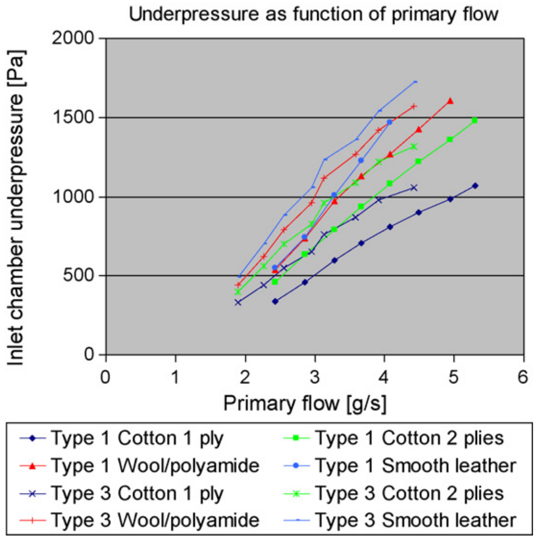

Fig. 8. Underpressure as function of primary flow for textile and leather specimens, ejectors types 1 and 3.

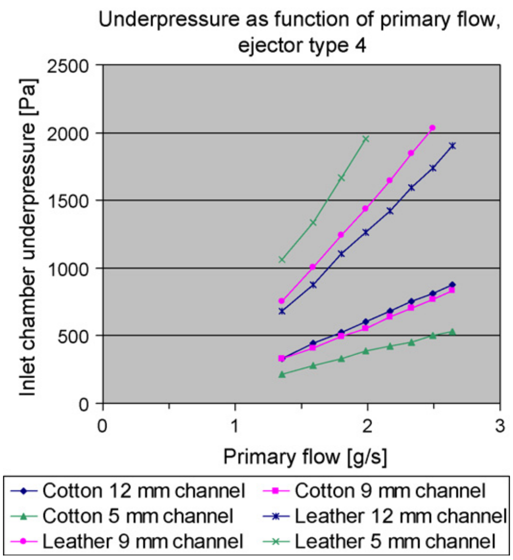

Fig. 9. Underpressure as function of primary mass flow for single sided planar Coanda ejector. Throat and diffuser channel width varied in the range 5–12 mm.

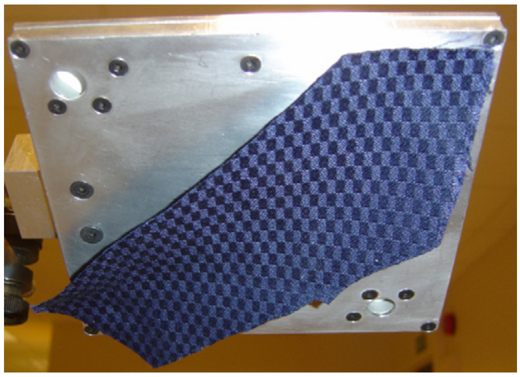

Fig. 10. Four ejector head Coanda gripper picking up textile specimen utilizing two ejector heads.

application. Grippers with a thickness in the range 10–30 mm give good performance for textile handling.

The advantage of this multi-head gripper is that each ejector operates as an independent suction head. For that reason the gripper will pick up textiles or other limp sheet material of any shape provided that enough suction heads get in contact with the material to create sufficient lifting force. Fig. 10 shows a four head planar ejector.

The Coanda ejector is also suitable for food material handling. It creates sufficient suction force for use in multi-head grippers for fish fillets and meat slices. The ejector is self-cleaning which makes it easy to obtain hygienically safe operations.

8. Conclusion

The tests reported here have demonstrated that the planar Coanda ejector functions just as well as standard cylindrical Coanda ejectors. It has further been demonstrated that both single sided and double-sided ejectors planar ejectors work satisfactorily. Furthermore the following rough design rules have been established:

- Coanda suction ejectors should have a diffuser length around eight times the diffuser width.
- Single sided planar Coanda suction ejectors should have height/width ratio 2 for the diffuser.

The advantages of Coanda ejectors for suction gripping of limp materials are:

- All materials ranging from impermeable to very loose fibrous materials can be gripped by suitable sizes of ejectors and secondary inlets.
- Slim multi-head suction grippers with independent suction heads can easily be built.
- The suction grippers leave no marks on any tested material types.
- Patent is pending for the planar Coanda ejector.

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