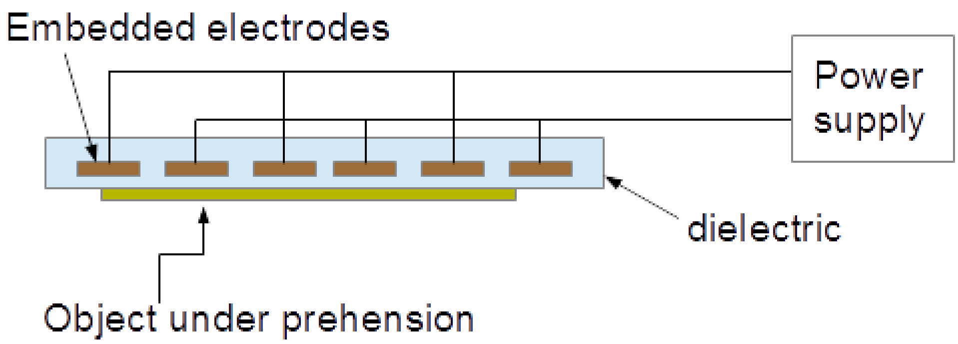
A brief history of electroadhesion

Electrostatic attraction was known to the ancient Greeks and the ability to charge an ebony rod when rubbed against a cat skin to attract small particles is known to every school child with an interest in science[1]. However, industrial applications are really limited to the later industrial period and are mainly concerned with the attraction of particles. Examples include electrostatic precipitation, filters, spray painting, imaging for photocopies to name but a few. The first use of electroadhesion for sheet components was in the retention of paper for the early flat-bed plotters in the 1960s[2]. Around this time NASA experimented with a electroadhesive devices to allow astronauts (and robots) to walk around on the surfaces of space vehicles[3].

With advances in the semiconductor industry, electroadhesion was implemented for the retention of wafers using so called „electrostatic chucks“[4]. These are implementable in vacuum where conventional suction systems are not. Many systems are commercially available[5].

The entry of electroadhesion into robotics really came in the 1980s with a number of innovations in the handling of sheet materials including polymers[6], Textiles[7] and carbon fibre[8].

The design of electroadhesive robot grippers is relatively simple[9].



The principle of electroadhesion can be basically split into 2 different principles: When used to prehend electrically conducting objects the basic Gauss theorem may be used:

$$D = \varepsilon E$$

The calculation of prehension forces is now trivial[10]. Those who have experimented with electroadhesion know that the forces generated appear to considerably lower than those expected from calculation. This has a number of reasons. There is no such thing as a homogeneous dielectric[11]. The contact between dielectric and object is never perfect. The use of mechanically compliant dielectrics (or even fluid backed dielectrics) can held significantly in this respect[12].

When used with electrically insulating objects the simple capacitor equations can no longer be used and the dielectric polarization must be considered:

$$D = \varepsilon E + P$$

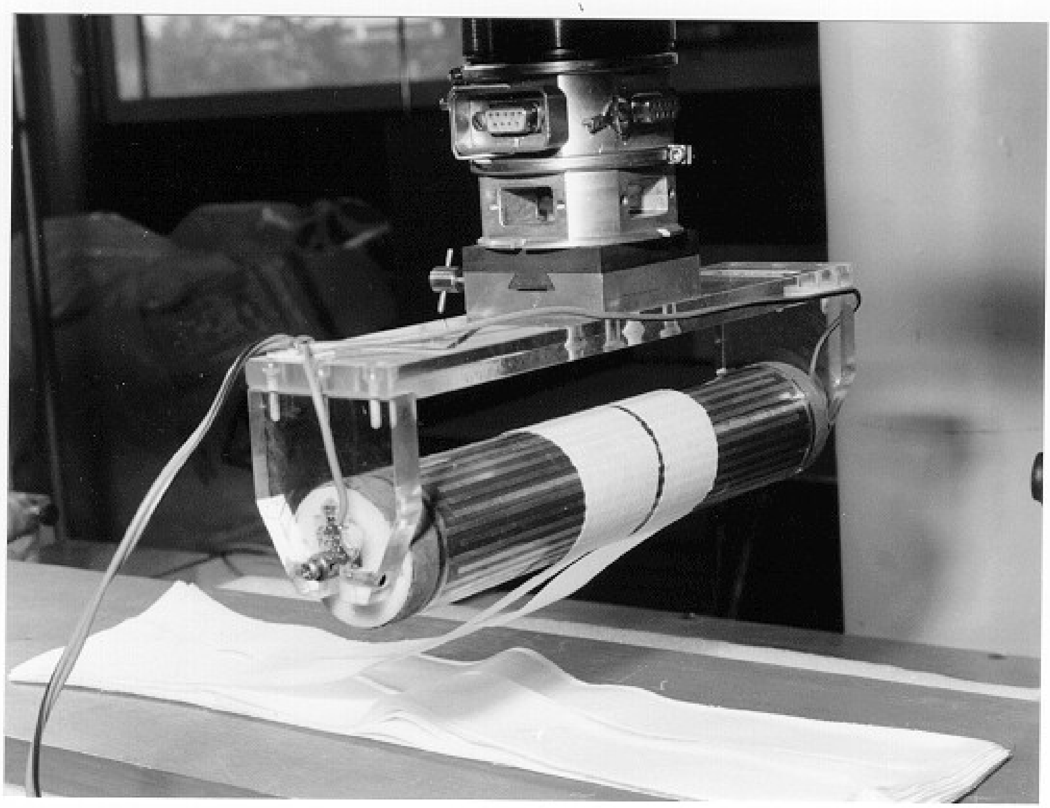
The polarization is frequency dependant and can take up to 4 different forms: electronic, atomic, orientation (molecular) and space charge (interfacial)[13]. The latter two are of most significance to electroadhesion. The significance of the frequency dependence becomes apparent when the dielectric relaxation time is considered[14].

The molecular polarisation of a materials is an exponential function of the dielectric relaxation time. Consequently, materials with a rapid dielectric relaxation time make poor candidates for electroadhesion (Nylon for example). At this point it must be stressed that charge generation and charge retention are not the same thing. Rubbing nylon results in static electricity but the material readily looses its charge, whereas PVC has little or no tribocharging ability but holds charge for a long time).

At an interface between two dielectrics, the difference in polarisation is the basic mechanism behind electroadhesion. Unfortunately, without knowing the exact molecular structure and dimensions of the two dielectrics it is impossible to make accurate calculations of force. In cases where the dielectric relaxation time is fast, the use of AC (or pulsed DC) fields is often advantageous[12].

An often heard myth in electrostatics is that charging reduces with increasing humidity. This is not completely wrong but very economic with the truth. Most materials initially experience an increase in charging with humidity until a peak is reached at point between 30% and 60% rH (depending on the material in question). After this the charging decreases[15].

Based on the understanding of these principles the first elecroadhesive robot grippers were designed in the 1980s and 90s and some even marketed as commercial products. The objective in the textile industry was to separate a single ply from a stack of the same (die cutting being the accepted technology of the time). To humans, with adept fingers, this may seem trivial. However, to a robot with a planar gripping surface it is not. For this reason cylindrical gripping heads were developed.



This allows the uppermost panel to be peeled from a stack leaving the others undisturbed and ready for the next prehension cycle[16].

Because robots are more expensive than people, robotics never really made much headway in the textile industry during the 1990s and electroadhesion was relegated to interesting but niche applications.

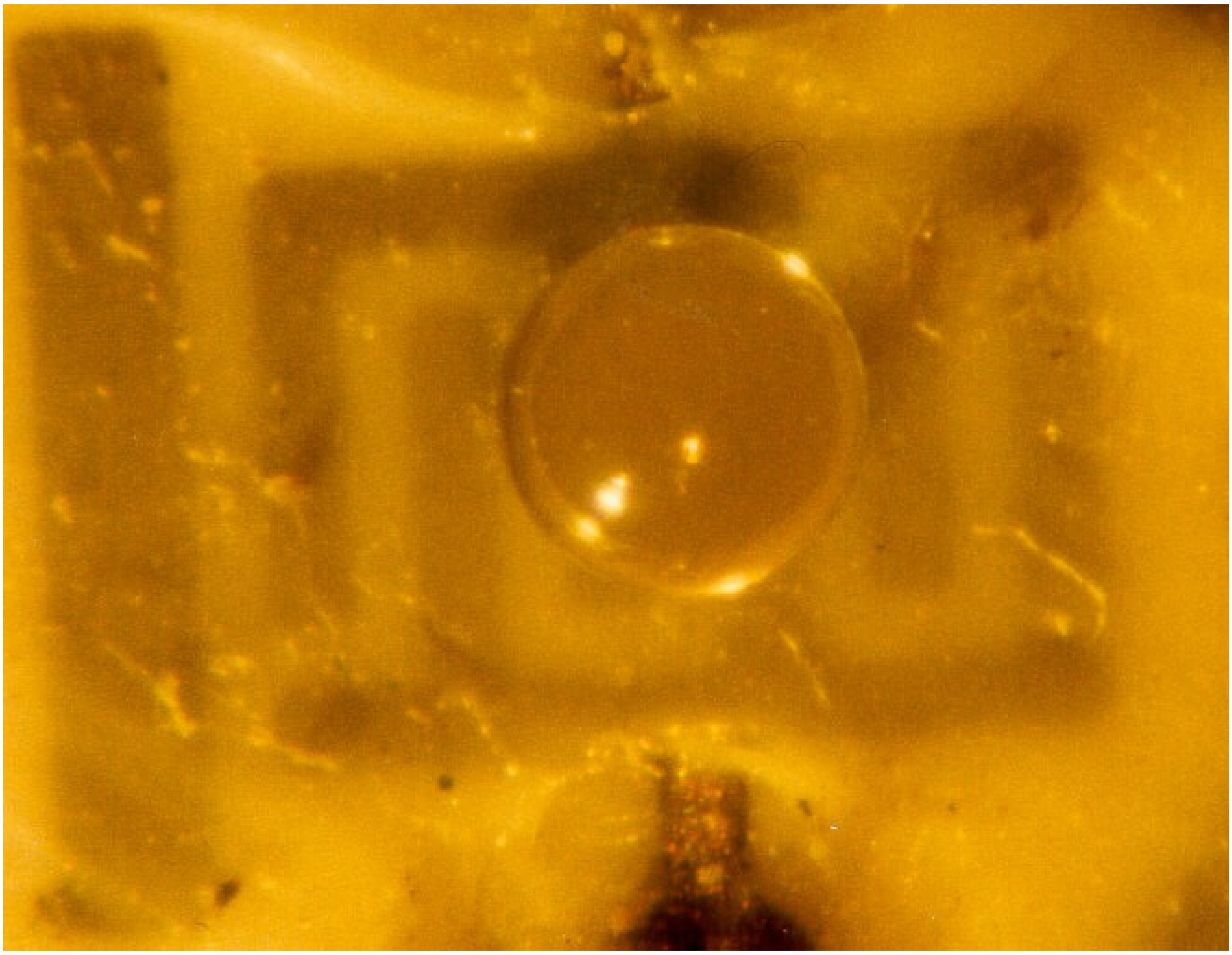
An interesting example is the retention of lepidoptera for visual inspection and image processing[17].

One area where electroadhesion is particularly applicable is in microsystems manufacture. When compared with a magnetic field in an electrodynamic machine, the energy density of an electrostatic field in a similarly dimensioned machine is considerably less[18]. This results from the fact, known to every TV serviceman who has worked with CRTs, that the maximum attainable field strength in air is about 30,000 Volts per cm. However, when dimensions are significantly decreased (in the µm range) this simple rule no longer holds true.

A rough rule of thumb becomes:

$$E_{MAX} = 3000 \cdot \frac{V}{mm} + \frac{500 \cdot V}{d[mm]} | d < 1\,mm$$

This means that significantly greater field strengths, and consequently larger prehension forces can be obtained. This resulted in the first electroadhesive microgrippers[19].



Since the advent of lightweight technology, devices with much improved energy densities (NdBFe magnet based motors, Lithium based batteries etc.) have changed the world of mobile robots considerably. The original concept of electroadhesion for wall climbing investigated by Krape (and others) during the 1960s is now realisable in the form of small mobile robots.

If you have any interesting facts or anecdotes to add then please contact:
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References

1. Trevena. D.H. - *Static Fields in Electricity and Magnetism* – Butterworths, London, 1961.

2. HP 9125A Flatbed Plotter 1968 - http://hpmuseum.net/display_item.php?hw=82

3. Krape R.P., - Applications Study of Electroadhesive Devices. - *NASA report CR-1211*, Chrysler Corp. Space Division. 1968.

4. Monkman G.J. - Workpiece Retention during Machine Processing - *Assembly Automation* - Vol 20, issue 4, MCB University Press, 2000.

5. ElectroGrip - *Principles of Electrostatic Chucks* - Principles1 rev4 March 2013

6. Abrarov. V.N. Et al. - Investigation of the limiting characteristics of electrostatic gripping devices in robot technology – *Soviet Engineering Research* vol 65, Iss 4, 1985.

7. Monkman G.J., Taylor. P.M. and Farnworth. G.J., - Principles of Electroadhesion in Clothing Technology. - *Intl. Journ. of Clothing Science and Technology.* 1 (3): 14-20., 1989.

8. Chen. X.Q. & Sarhadi. M, - Investigation of Electrostatic Force for Robotic Lay-up of Composite Fabrics. - *Mechatronics*. 2(4): 363-374. 1992.

9. Monkman. G.J., S. Hesse, R. Steinmann & H. Schunk – *Robot Grippers* - Wiley, Berlin 2007.

10. Monkman. G.J. - An analysis of astrictive prehension - *International Journal of Robotics Research* - Vol 16, No. 1 - February 1997.

11. Moore, A.D. (Ed.) - *Electrostatics and its Applications* – John Wiley, 1973.

12. Monkman. G.J., - Compliant Robotic Devices and Electroadhesion - *Robotica* Vol 10, pp. 183-185., 1992.

13. Von Hippel, A.R. - *Dielectrics and Waves* - Wiley, 1954.

14. Zoril, U.Z. © Elektrostatische Adhasionswirkungen - Adhasion - Heft 5/6, pp 142©149, 1976.

15. Sereda, P.J. & R.F. Feldman - Electrostatic Charging on Fabrics at Various Humidities - *Journ. Textile Inst.* Vol 55, pp T288-T298, 1965.

16. Monkman. G.J. - Sensory Integrated Fabric Ply Separation - *Robotica* - Vol 14, pp114-125 - Cambridge University Press 1996.

17. Chesmore, D. & G.J. Monkman. 1994. Automated Analysis of Variation in Lepidoptera. *The Entomologist*. Vol 113, Nos. 3 & 4, pp 171-182.

18. Gray. C.B. - *Electrical Machines and Drive Systems* – Longman, New York, 1991.

19. Monkman. G.J. - Electroadhesive Microgrippers - *Assembly Automation* - Vol 24, No. 1, pp 326-330 - MCB University Press, October 2003.