CURRENT STATE AND PROSPECT OF STUDY ON DE-ICING OF POWER TRANSMISSION LINES USING MECHANICAL DEVICES

Yang Jialun*, Zhu Kuanjun, Liu Bin
Engineering Mechanics Research Department, China Electric Power Research Institute, Beijing, China
*Email: yangjialun@epri.sgcc.com.cn or jialunyang@gmail.com

Abstract: Accumulated ice on power transmission lines may cause mechanical and electrical problems to power lines and towers, which means that the successful de-icing of power lines plays a key role for the guarantee of safety of power transmission. The purpose of this paper is two-fold. First, the state of the art of the de-icing devices has been reviewed and the current mechanical devices have been classified through three criteria which are the function position, the de-icing principle, and the mechanical structure, respectively. Second, the prospect on the de-icing of power transmission lines using mechanical devices has been discussed with the aim of providing insight into the innovation design of de-icing mechanical devices for power transmission lines.

1. INTRODUCTION

De-icing of overhead power lines using mechanical devices require much less energy compared to the thermal methods. Moreover, it is more suitable to be utilized for the de-icing of ground wires since the insulation from the tower is necessary when making use of Joule-Effect method to melt ice. Consequently, this paper will focus on the current state of the mechanical de-icing devices.

2. RESULTS AND DISCUSSION

The mechanical de-icing devices are classified by three criteria which are the function position, the de-icing principle, and the mechanical structures, respectively.

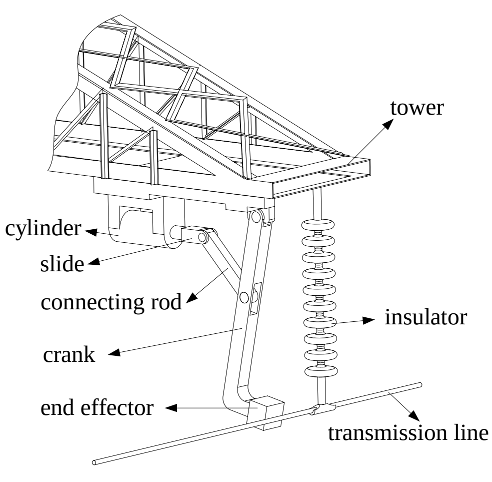

Figure 1: Sketch of the CEPRI-DI1

For instance, the function position of the CEPRI-DI1 depicted in Fig. 1 is fixed; the de-icing principle is vibrating and shocking; and the mechanical structure is planar four bar mechanism. Some typical characteristics of the mechanical de-icing devices are listed in Table 1.

Table 1: Characteristics of mechanical de-icing devices

Criteria	Characteristics
Function position	How to put the de-icers into the function position should be taken into account, since normally it is impossible for linemen to reach the tower due to the accumulated ice. On the other hand, in case of the fixed function position, the de-icers can be started remotely without the need of reaching towers.
Breaking ice principle	For twisting principle, it is difficult to be employed for bundles of cables due to the existence of spacers. In case of cutting principle, the cutter should be designed carefully without damaging the power lines. If the mixed principle is employed, the system complexity should be taken into account.
Mechanical structures	For the mechanical structures utilizing the effect of spring, the whole system will be more compact compared to the system employing planar four bar mechanism. However, when the amplitude and frequency of the generated vibration to power lines is not fixed, the planar four bar mechanism may be necessary.

3. CONCLUSION

The current state of the mechanical de-icing devices for overhead power transmission lines is discussed and the mechanical devices are classified by three criteria. For solve the challenges ahead in terms of the de-icing issue using mechanical devices, appropriate criteria should be established for the evaluation of de-icing devices, such as energy consumption, speed, maintenance, cost, difficulty of operation. Moreover, some mathematical tools can be utilized for the novel design of mechanical de-icing devices. The authors believe that through analyzing the existing devices used for de-icing of power transmission lines and utilizing the proposed synthesizing methodologies, novel concepts of mechanical devices may be proposed for the de-icing operation with better performance. The goal of improving customer service, benefiting power companies and maintenance companies may be realized in the future.

4. REFERENCES

[1] M. Farzaneh, Atmoshperic icing of power networks, Springer: Berlin, 2008.

[2] A. Leblond, S. Montambault, M. St-Louis, et al. “Development of new ground wire de-icing methods,” Proceedings of the 10th International Workshop on Atmospheric Icing of Structure, Brno, 2002, pp.1-6.

[3] A. Leblond, B. Lamarche, D. Bouchard, et al. “Development of a portable de-icing device for overhead ground wires,” Proceedings of the 11th International Workshop on Atmospheric Icing of Structures, Montreal, 2005, pp. 399-404.

Current state and prospect of study on de-icing of power transmission lines using mechanical devices

Yang Jialun, Zhu Kuanjun, Liu Bin
Laboratory of Conductors and Fittings
Engineering Mechanics Research Department,
China Electric Power Research Institute
Beijing, China
yangjialun@epri.sgcc.com.cn or jialunyang@gmail.com

***Abstract*—Accumulated ice on power transmission lines may cause mechanical and electrical problems to power lines and towers, which means that the successful de-icing of power lines plays a key role for the guarantee of safety of power transmission. The purpose of this paper is two-fold. First, the state of the art of the de-icing devices has been reviewed and the current mechanical devices have been classified through three criteria which are the function position, the de-icing principle, and the mechanical structure, respectively. Second, the prospect on the de-icing of power transmission lines using mechanical devices has been discussed with the aim of providing insight into the innovation design of de-icing mechanical devices for power transmission lines.**

Keywords-de-icing; power transmission lines; mechanical devices; classification; de-icing

I. INTRODUCTION

Accumulated ice on overhead transmission lines may exist in many countries, such as United States, Canada, Russian, France, Finland, Sweden, Japan, and China [1], which can cause huge disasters. For instance, the snow and ice disaster happened in Southern China during Jan. to Feb. 2008 resulted in galloping of power transmission lines and collapsing of transmission towers [2], from which we can see that the technique regarding de-icing devices is very important. The cost of repairs of the power grid is very high, and the cut-off of power supply is a serious problem for customers, power companies, and line companies.

Normally, there are mainly four methodologies employed for de-icing of power transmission lines, including thermal, passive, mechanical, and miscellaneous, respectively. In particular, thermal methods refer to shed the ice on transmission lines by melting, which has been applied in field lines. Some recent thermal methods for the de-icing issues are introduced in [3-6]. It is worth to note that when applying Joule-Effect method to de-ice the ground wires, the ground wires should be insulated from the tower, which will increase the complexity of the de-icing system and the cost of de-icing. Moreover, passive methods are those making use of natural forces, such as wind, gravity, and temperature variations to shed ice. However, the de-icing effects of passive methods are limited and the reliability of the passive methods can not be guaranteed. On the other hand, mechanical methods for de-icing of overhead transmission lines denote to those using force to cause the shedding of ice from power lines. Compared to the thermal methods, mechanical methods require much less energy due to the brittle characteristics of the deposit ice on power lines [7, 8]. Moreover, from the mechanical properties of ice and snow, we can see that the mechanical method will not damage the conductors and ground wires, as well as insulator strings and other fittings [8], given the fact that the mechanical de-icing devices are designed carefully.

There have already been several papers dealing with the state of the art of de-icing and anti-icing of power transmission lines [9-13]. However, few papers have focused on the state of the art of the de-icing devices form the mechanical engineering point of view. Consequently, we will discuss the state of the art and prospect of de-icing of power transmission lines using mechanical devices, which is belonging to the mechanical method of de-icing. There are about 100 patents[14] have been analyzed. Several mechanical devices have been illustrated to show the idea of de-icing operation using mechanical devices.

II. CURRENT STATE

As long as the customers, power companies, and line companies suffered a lot from the accumulated ice on power lines, more and more researchers have paid due attention to the de-icing issue by means of mechanical devices. Several prototypes have been developed and tested in test lines or field lines, as well as many conceptual designs. For instance, around 100 patents related to the de-icing issue on power lines have been published [14], coming from US, Japan, Germany, Russian, and China, etc. Due to space limitation, only some typical patents have been included in the reference list of this paper.

In order to make it easier to understand the mechanical de-icing devices and achieve deeper insight into the innovation design of de-icing mechanisms, we will classify the mechanical devices through three criteria which are the function position, the de-icing principle, and the mechanical structure, respectively.

A. Classification via function position

Generally speaking, the function position of the de-icing devices plays a key role in determining the operation complexity of the de-icing process due to the fact that the power lines are not easy to be reached when accumulated with ice. As can be seen from Fig. 1, the function positions of the de-icing devices can be categorized into movable position and fixed position. Furthermore, the movable positions can be further classified into three kinds, which are transmitted by robots, shooting, and dragging by ropes, respectively.

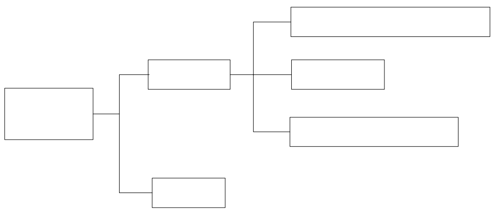

Figure 1. Different de-icing mechanisms classified via function position

Some mechanical de-icing devices are mounted in maintenance robots to remove the accumulated ice. As a result, the de-icing devices are moved by the robots. For the development of maintenance robots, interested readers are suggested to refer to the review paper in terms of transmission line maintenance robots [15]. On the other hand, some de-icing devices are integrated into a special designed robot, such as the Remotely Operated Vehicle (ROV for short) de-icer introduced in [16, 17]. In Fig. 2, we can see that the ROV de-icer is shedding the accumulated ice on power lines.

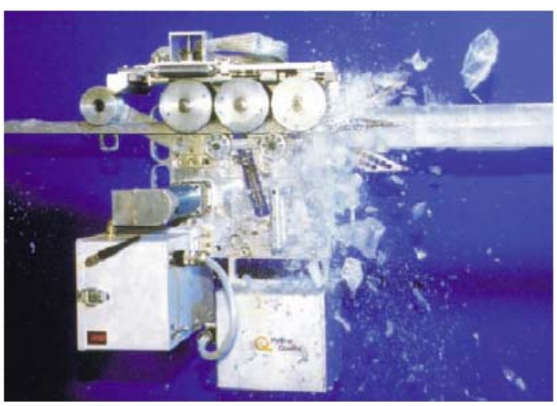

Figure 2. Prototype of the ROV de-icer

It is not difficult to know that the accreted ice can be forced to shed by shocking. Based on this idea, a specially designed bow has been proposed [18], which is able to shoot objects such as columniform icicles, crabsticks to generate shocks onto the accumulated ice. In this case, there is no need for the lineman to reach the power lines, which will reduce the risk of de-icing.

In Fig. 3, the De-icer Actuated by Cartridge (DAC for short) [19] prototype is held in place by a rope. After firing the DAC, vibration will be generated onto the power lines, which will force the deposited ice to shed from the power lines. However, it is difficult to employ the DAC for river crossings.

Figure 3. DAC prototype held in place by a taut rope and ready to be fired

Unlike the aforementioned devices whose function positions are movable, some de-icing devices are fixed on the tower or the power lines. For instance, an operatively controllable electromechanical vibrator is attached on a line section between towers [20]. When the accumulated ice is sensed, the vibrator will be actuated to force the ice to shed from power lines. Furthermore, the CEPRI-DI1 is illustrated in Fig. 4, which is mounted on the tower. The CEPRI-DI1 contains a crank-slide mechanism which is able to generate shock to the power lines. Note that the slide of the CEPRI-DI1 can be actuated by either pneumatic or hydraulic cylinder. The amplitude and frequency of the vibration to the power lines generated by the end-effector can be adjusted by suitable controller which is not shown in Fig. 4.

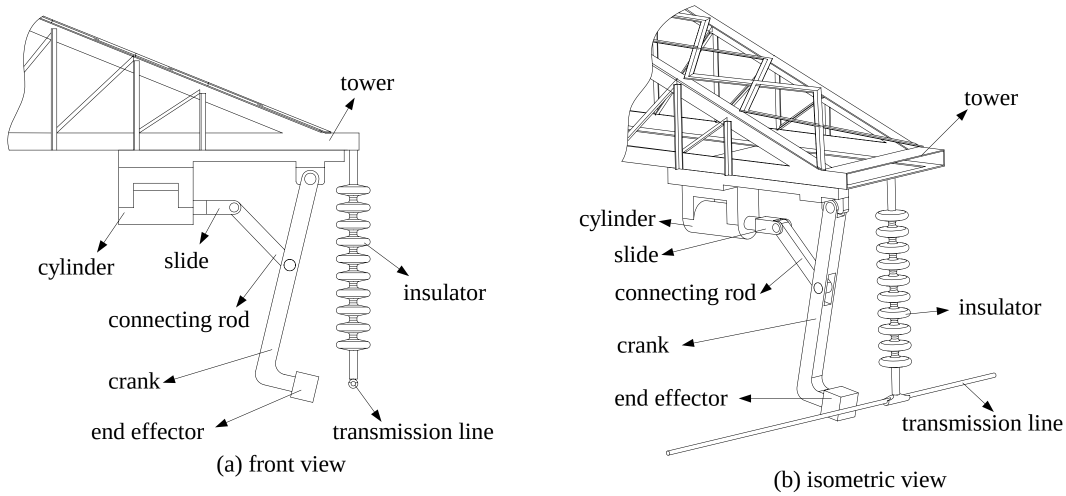

Figure 4. Sketch of the CEPRI-DI1

B. Classification via de-icing priciple

In Fig. 5, we can see that different de-icing principle may be applied for power lines using mechanical devices, including cutting, vibrating and shocking, twisting, and mixed with cutting, vibrating, shocking, and twisting.

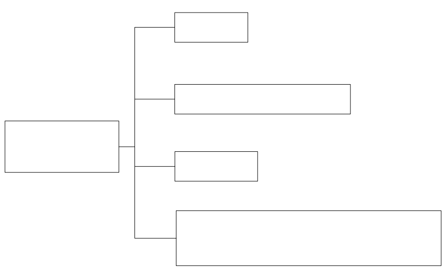

Figure 5. Different de-icing mechanisms classified via breaking ice principle

Currently, most of the mechanical devices make use of vibrating and shocking to shed the accumulated ice [21-23].

In [24], a de-icing mechanism consists of three milling cutter which are mounted on a power line robot. The milling cutters are mounted around the power line so that all the deposited ice around the power lines can be cut successfully. Along with the movement of the robot, the ice on the whole line section can be shed. It is not difficult to see that the ROV illustrated in Fig. 2 also shed the ice by cutting. The cutter should be designed carefully, since it is possible to damage the power lines if the cutter is close to the lines. On the other hand, if the cutter functions far away from the power lines, not all of the accumulated ice can be shed from power lines. Other examples using cutting principle are introduced in [25, 26].

Through twisting the cable for a predetermined number of turns within the elastic domain of the deformation of the cable, mechanical elastic energy can be accumulated in the cable. Then the cable is released and untwisted under the spring back effect, leading to the breaks of the deposited ice on the cable [27].

To achieve better de-icing effect, it is straightforward to employ multi de-icing principle to shed the accumulated ice [28, 29]. For instance, a de-icing robot is introduced in [29], where the ice deposited on the cables is shed through cutting and shocking. It is necessary to point out that integrating multi de-icing principles in a single unit will increase the complexity of the whole system, which may raise the cost and difficulty of maintenance and operation.

C. Classification via mechanical structures

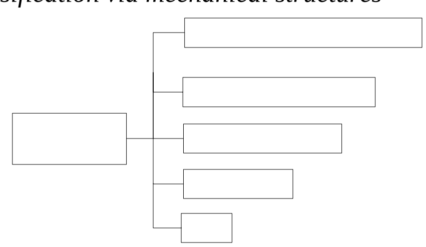

Figure 6. Different de-icing mechanisms classified via mechanical structures

Various mechanical structures have already been proposed to generate vibration and shock to the power lines and some of them are illustrated in Fig. 6. In particular, we can see that the CEPRI-DI1 depicted in Fig. 4 employs a slider-crank mechanism which belongs to planar four bar mechanism. On the other hand, many de-icing mechanisms are actuated by the effect of spring so that the end-effector of the de-icer can be shifted toward to power lines to generate vibration. However, the main difference lies in the mechanisms that make the end-effector move far away from power lines. For instance, in [30, 31], the de-icing mechanisms utilize gear and rack system to move the end-effector of the de-icer far away from power lines. In stead of using gear and rack system, cam can also be used to change the position of the end-effector of the de-icer [32]. Note that both the Cam and the planar four bar mechanism can be integrated together to force the ice shed from power lines [33].

Cutting

Vibrating, shocking

Breaking i

III. PROSPECT

One of the main objectives of designing the mechanical de-icing devices is to decrease the risk to customers, power companies, and line companies, which is caused by the accumulated ice on power lines. So the development of the mechanical de-icing devices should consider the characteristics of the current devices, which are listed in Tab. 1.

TABLE I. CHARACTERISTICS OF MECHANICAL DE-ICING DEVICES

Criteria	Characteristics
Function position	How to put the de-icers into the function position should be taken into account, since normally it is impossible for linemen to reach the tower due to the accumulated ice. On the other hand, in case of the fixed function position, the de-icers can be started remotely without the need of reaching towers.
Breaking ice principle	For twisting principle, it is difficult to be employed for bundles of cables due to the existence of spacers. In case of cutting principle, the cutter should be designed carefully without damaging the power lines. If the mixed principle is employed, the system complexity should be taken into account.
Mechanical structures	For the mechanical structures utilizing the effect of spring, the whole system will be more compact compared to the system employing planar four bar mechanism. However, when the amplitude and frequency of the generated vibration to power lines is not fixed, the planar four bar mechanism may be necessary.

Even there are many mechanical devices introduced in this paper, many of them are not tested in field lines and most of them are only conceptual designs. Consequently, the challenges ahead in terms of de-icing of power lines using mechanical devices are more efficient design and reliable experiments and tests in the field lines. The possible developments may be as follows.

- Appropriate criteria should be established for the evaluation of de-icing devices, such as energy consumption, speed, maintenance, cost, difficulty of operation.
- Systematic synthesizing methodology should be utilized for the novel design of mechanical de-icing devices from the mechanical point of view, such as screw theory [34], graph theory [35], G_F set theory [36, 37], Lie group theory [38, 39].
- The TRIZ [40] may be employed with the aim of innovative design and performance optimization of the mechanical de-icing devices.

IV. CONCLUSIONS

The current development of mechanical de-icing devices has greatly contributed to the enhancement of customer service, cost reduction, the work environment, and worker welfare. However, novel mechanical devices with better performance are still necessary to be developed.

The authors believe that through analyzing the existing devices used for de-icing of power transmission lines and utilizing the proposed synthesizing methodologies, novel concepts of mechanical devices may be proposed for the de-icing operation with better performance. The goal of improving customer service, benefiting power companies and maintenance companies may be realized in the future.

ACKNOWLEDGMENT

The comments from our colleges in the laboratory of conductors and fittings of CEPRI in terms of the de-icing issue on power transmission lines are highly appreciated.

REFERENCES

[1] M. Farzaneh, Atmoshperic icing of power networks, Springer: Berlin, 2008.

[2] X. Jiang, J. Zhao, B. Luo, et al. "Surevey and analysis of ice accidents of early 2008 in southern China," The 13th International Workshop on Atmoshperic Icing of Structures, Andermatt, Switzerland, 2009; pp. 1-7.

[3] P. Couture, "Smart power line and photonic de-icer concepts for transmissoin-line capacity and reliability improvement," Cold Regions Science and Technology, 2011, 65 (1), pp. 13-22.

[4] S. Fan, X. Jiang, C. Sun, et al., "Temperature characteristic of DC ice-melting conductor," Cold Regions Science and Technology, 2011, 65 (1), pp. 29-38.

[5] V. F. Petrenko, C.R. Sullivan, V. Kozlyuk, "Variable-resistance conductors (VRC) for power-line de-icing," Cold Regions Science and Technology, 2011, 65 (1), pp. 23-28.

[6] V.F. Petrenko, C.R. Sullivan, V. Kozlyuk, et al., "Pulse electro-thermal de-icer (PETD),". Cold Regions Science and Technology, 2011, 65 (1), pp. 70-78.

[7] T. Kalman, M. Farzaneh, G. McClure, "Numerical analysis of the dynamic effects of shock-load-induced ice shedding on overhead ground wires," Computers & Structures, 2007, 85 (7-8), pp. 375-384.

[8] J.J. Petrovic, "Mechanical proterties of ice and snow," Journal of Materials Science, 2003, 38 (1), pp. 1-6.

[9] J.C. Polhman, P. Landers, "Present state-of-the-art of transmission line icing," IEEE Transactions on Power Apparatus Systems, 1982, PAS-101 (8), pp. 2443-2450.

[10] E.P. Lozowski, J.F. Gayet, "Atmospheric icing: a review," The 4th International Workshops of Atmospheric Icing of Structure, Paris, France, 1988, pp. 1-6.

[11] P. Admirat, Y. Sakamoto, "Wet snow on overhead lines: state-of-art," Proceedings of the 4th International Workshop on Atmospheric Icing of Structures, Paris, 1988, pp. 8-13.

[12] M. Hydro, "Ice strom management of overhead lines," CEA Workshop, 1993.

[13] J. L. Laforte, M.A. Allaire, J. Laflamme, "State-of-the-art on power line de-icing," Atmospheric research, 1998, 46 (1-2), pp. 143-158.

[14] Technical Report, Patent analysis in the field of mechanics of transmission line, Beijing, 2010, pp. 1-53.

[15] K. Toussaint, N. Pouliot, S. Montambault, "Transmission line maintenance robots capable of crossing obstacles: state-of-the-art review and challenges ahead," Journal of field robotics, 2009, 26 (5), pp.477-499.

[16] A. Leblond, S. Montambault, M. St-Louis, et al. "Development of new ground wire de-icing methods," Proceedings of the 10th International Workshop on Atmospheric Icing of Structure, Brno, 2002, pp.1-6.

[17] S. Montambault, C.J. St-Louis, "Preliminary results on the development of a teleoperated compact trolley for live-line working," 2000 IEEE ESMO Conference, Montreal, Canada, 2000, pp. 21-27.

[18] Z. Zhang, D. Zhang, L. Zhang, "A de-icing method and a de-icing device for safely de-icing of power lines," 200810014592.7[P], China, 2008.

[19] A. Leblond, B. Lamarche, D. Bouchard, et al. "Development of a portable de-icing device for overhead ground wires," Proceedings of the 11th International Workshop on Atmospheric Icing of Structures, Montreal, 2005, pp. 399-404.

[20] R. Hansen, "Means and method for removing extraneous matter like ice and snow from an overhead line," US 2004/0065458 A1[P], Unite Sates, 2004.

[21] Y. Yang, H. Gao, S. Meng, et al., "Structural design of overhead line deicing robot," Electric Power Construction, 2009**,** 30 (3), pp. 93-96.

[22] I. Masaaki, T. Shigeru, "Snow remover by shock of overhead power transmission line," JP2004239037 [P], Japan, 2004.

[23] A. Nourai, R.M. Hayes, "Power line ice-shedder," US 6660934 B1[P], Unite States, 2003.

[24] B. Qu, "De-icing devices for overhead lines," 200810124500.0[P], China, 2008.

[25] C. Wang, S. Wei, Q. Liao, "Design of a robot for deicing high voltage transmission lines," Mechanical engineering and autoation 2010**,** 158 (1), pp. 148-149.

[26] J. Zhao, R. Guo, L.Cao, et al. "De-icing cutter for overhead transmission lines," ZL 200920020033.7[P], China, 2010.

[27] M.A. Allaire, J.L. Laforte, "Method and apparatus for breaking ice accretions on an aerial cable," US 6518497 B1[P], Unite States, 2003.

[28] W. Sun, C. Wang, Y. Wang, et al. „De-icing mechanisms mounted on a robot for high voltate power transmission lines," 200910310514.6[P], China, 2010.

[29] H, Li, X, Li, Y. Chen, et al. "De-icing devices for the high voltage power lines," ZL 200820079832.7[P], China, 2009.

[30] J. Tan, J. Ma, Y. Xia, et al. "De-icing devices for power lines," ZL 200820231973.6[P], China, 2009.

[31] C. Luo, "Means for de-icing on high voltage power transmission lines," ZL 200820228457.8[P], China, 2010.

[32] H. Wang, K. Xuan, S. Tian, et al. "De-icing devices for high voltage power transmission lines," ZL 200920026836.3[P], China, 2010.

[33] X. Ying, "Means and its controller for de-icing on power transmission lines," ZL 200820090281.4[P], China, 2009.

[34] Z. Huang, Q. Li, "General methodology for type synthesis of symmetrical lower-mobility parallel manipulators and several novel manipulators," The International Journal of Robotics Research, 2002**,** 21 (2), pp. 131-145.

[35] Y. Lu, L. Ding, J. Xu, "Autoderivation of topological graphs for type synthesis of planar 3DoF parallel mechanisms," Journal of Mechanisms and Robotics 2010, 2 (1), pp. 011001.

[36] F. Gao, J. Yang, Q.J. Ge, "Type synthesis of parallel mechanisms having the second class G_F sets and two dimensional rotations," Journal of Mechanisms and Robotics, 2011**,** 4 (1), pp. 011003.

[37] J. Yang, F. Gao, Q.J. Ge, et al., "Type synthesis of parallel mechanisms having the first class G_F sets and one dimensional rotation," Robotica, in press.

[38] J.M. Herve, "The Lie group of rigid body displacements, a fundamental tool for mechanism design," Mechanism and Machine Theory, 1999**,** 34 (5), pp. 719-730.

[39] J. Meng, G. Liu, Z. Li, "A geometric theory for analysis and synthesis of sub-6 DoF parallel manipulators," IEEE Transactions on Robotics, 2007**,** 23 (4), pp. 625-649.

[40] G. Altshuller, Inovation algorithm: TRIZ, systematic innovation and technical creativity, Technical Innovation Center Inc: Worcester MA, 1999.