

# Function Analysis and Structural Design of Tubular Carry System

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**Abstract**—The Tubular Carry System is a pipe rack suspension system specially designed for large-capacity outdoor backpacks, which is representative. Through the analysis of the lightweight function, stabilization function, ventilation function and adjustable function of the TCS Suspension System, the structure design to realize its good functionality is explored. And on the basis of the TCS Suspension System, the back panel split structure, the internal ventilation structure and the movable waist belt structure are designed to better achieve the effects of reducing the weight of the bearer, fitting the human body, stabilizing and comfortable, and ventilating. By analyzing the function and structural design of the TCS Suspension System, it can provide a valuable reference for outdoor backpack design.

**Keywords**:- *TCS Suspension System; outdoor backpacks; carrying comfort; functionality*

## I. INTRODUCTION

In outdoor sports, the enthusiasts often face extreme weather and harsh environments, so excellent outdoor equipment is indispensable for them. Outdoor backpacks need to store food, clothes, and tools necessary for the journey, and its importance is self-evident. In addition to a reasonable storage space, a good weight reduction design, and high-quality breathable fabrics for outdoor backpacks, the functionality of its suspension system is the most important thing. The TCS suspension system has made great innovations and reforms in the carrying experience of outdoor backpacks. Its lightweight function is excellent, it breaks the traditional support method, so that the user's load during walking can be reasonably distributed, which greatly improves the user's carrying comfort. In addition to lightweight, the TCS suspension system also has ventilation, stabilization and adjustable functions, taking into account the various needs of users, and opening a new chapter of "perfect backpacking" in outdoor sports.

## II. OVERVIEW OF TCS SUSPENSION SYSTEM

The full name of TCS is Tubular Carry System, which is a pipe rack carrying system developed and designed by the German company BIGPACK specifically for climbing. Generally speaking, the composition of the carrying system includes shoulder straps, waist belts, chest straps, shoulder stress belts, bottom stress belts, support devices, ventilation devices and adjustment devices [1]. In 1996, the German company BIGPACK first used the TCS suspension system on

its Performic series of backpacks, and filed a patent application all over the world, which changed the traditional backpack system supported by U-shaped tubes or double aluminum bars. In 1998, the Performic series backpack won the German Outdoor Award. Breakthrough innovation and user-friendly design have enabled the TCS backpack system to take the lead in the European mountaineering bag backpack performance evaluation for six consecutive years, and is known as the "intelligent backpack system" [2].

BIGPACK, which developed the TCS, was founded in 1976 in Stuttgart, Germany. BIGPACK believes that innovation is the cornerstone of brand development. The company continues to develop new products, insists on promoting the development of outdoor sports, and launches high-quality, breakthrough products. BIGPACK agreed with that carrying equipment is the guarantee for outdoor explorers to go to nature and experience nature. It is the original intention of BIGPACK to develop the TCS to allow explorers to explore the wasteland, climb dangerous peaks, hike the jungle without worry, and enjoy the joy and passion of the adventure.

TCS has condensed decades of hard work of BIGPACK. Its characteristic is that it can be reliably combined with the carrier without hindering the natural body movement of the carrier, reducing the burden on the back, and evenly distributing the load on the human body. Achieved a breakthrough innovation in the carrying system. As shown in Figure 1. Prior to this, outdoor backpacks often faced problems of insufficient load or stiffness. Lightweight backpacks do not have a tube carrying system and can be folded flexibly, but they can only carry lighter weight and volume, which is difficult to meet the needs of long-distance outdoor explorers; while U-tube or double aluminum pipe outdoor backpacks with large load capacity. It can disperse the gravity better, but the comfort is insufficient and the self-weight is large, which tends to restrict the user's body movement, and it is difficult to adapt to outdoor activities with large body movement.



Fig.1 PERFORMIC + 60III TCS.

The TCS is mostly used on large backpacks with a carrying capacity of 50L-70L and above, and the use scene is "climbing". The reason why the TCS is positioned as a "climbing" use is that it is more closely integrated with the backpack and body, and has a good fit. This feature is particularly important for "climbing", which ensures the safety and balance of the user during the climbing process, saves effort, and can reduce the user's sense of weight. On the external hanging system, you can carry equipment required for climbing such as helmets, trekking poles, and snow spikes. At the same time, the U-shaped aluminum tube and H-shaped double titanium strip composite structure of the TCS has the characteristics of high strength and resistance to deformation, which is suitable for outdoor activities with high load and long cycle.

According to the official website of BIGPACK, the backpacks using TCS suspension system mainly include ATLAS 50L, ATLAS 60L; PERFORMIC+ 60 II, PERFORMIC + 60 III; EXPE 70, EXPE 80.

The ATLAS series is made of durable CORDURA fabric. The ATLAS series backpack combines traditional backpack functions and stylish design, suitable for long journeys and travel.

The PERFORMIC series has been launched to the third generation. The PERFORMIC is a classic backpack equipped with the TCS suspension system. The second and third generations have absorbed the classic design of the original backpack and upgraded the fabric and details. The third-generation backpack adopts a streamlined design, a multi-functional external hanging system and an adjustable hood, and can be equipped with a water bag system. Suitable for trekking.

The EXPE series uses the current advanced technology and has good fit, support and durability. This series of backpacks are also made of strong CORDURA fabric and adopt the innovative TCS to further enhance the comfort of carrying. The capacity of this series of backpacks is divided into 70L and 80L, which is the largest capacity backpack series launched by BIGPACK.

### III. TCS FUNCTION ANALYSIS

The TCS suspension system is an adjustable tubular aluminum strip combined bracket carrying system. A hidden adjustment device is installed behind the back pad, which is ergonomically designed, supplemented by a lightweight aluminum bracket, to maximize the distribution and transfer of the load. It has lightweight function, stabilization function, ventilation function and adjustable function.

#### A. *Lightweight function*

The lightweight design of the TCS is mainly composed of two aspects: First, reduce the weight of the backpack. The purpose of reducing the weight of the backpack is achieved by changing the support structure of the backpack and the material of the back frame; second, the uniform transmission of gravity reduces the weight of the user. Through the reasonable structure of the backpack, the gravity is evenly transmitted to the best load-bearing part of the human body, so as to achieve the purpose of reducing the weight-bearing feeling.

In order to support and reduce the weight of the backpack, the early outdoor backpacks mainly adopted U-shaped tubes and double aluminum strip support devices, which were then changed to "□" shaped aluminum sheets supplemented by pad support [4]. The TCS breaks the traditional aluminum frame support and adopts a unique U-shaped aluminum tube and H-shaped double titanium strip composite design, which greatly reduces the weight of the backpack. Regarding the choice of the material of the metal tube frame, both titanium alloy and aluminum-magnesium alloy are aerospace metals with high strength, good rigidity and light weight, which meets the lightweight needs of outdoor backpacks [5]. In the choice of fabrics, the TCS usually selects light-weight, quick-drying and wear-resistant fabrics in order to reduce the weight of the backpack. BIGPACK chooses CORDURA as the main material for outdoor hiking and mountaineering bags. The fabric uses high-strength fiber technology and has good wear resistance, tear resistance and puncture resistance [6]. The fabric selection of the shoulder strap, waist belt and back pad is different from that of the bag body. Many rectangular holes are punched in the material to form a 3D mesh structure to reduce the weight of the backpack, and make the shoulder strap and waist belt better bend and more breathable to enhance carrying comfort. At the same time, the buckle uses UTX buckle, which is durable and lightweight.

In the design of gravity transmission, a reasonable weight-bearing ratio should be 80% on the waist and back and 20% on the shoulders [7]. The TCS cleverly transfers the load to the human lumbar spine and shoulder stress points in a reasonable proportion, and uses the reasonable combination of three layers of hip belts to provide a good weight distribution [8] and effectively distribute the weight to the third lumbar vertebra. This area makes the waist and back the main load-bearing part and reduces the load on the shoulders. The user "wears" the backpack like clothes to enhance the user's comfort. At the same time, the TCS is designed with an internal plastic shell on the back, which can effectively prevent the heavy objects in the bag from compressing the back, further reducing the weight-bearing feeling and achieving lightweight functions.

#### *B. Stability function*

The stability function of the backpack is an important function of making the backpack fit the human body during the traveling process of the user. The wide back cushion and elastic straps of the TCS, as well as a strong wrapping waist belt, enable the backpack to be relatively static with the back during human movement, ensuring that the backpack and the human body are stable when the user is outdoors, reducing the sense of shaking.

In the realization of the stability function, the strap design plays an important role. The strap and back pad are in direct contact with the human body, which is the connection that guarantees the reliable combination of the backpack. The main shoulder strap of the TCS uses an "S" design to balance the weight of the shoulders, and can go around the neck, allowing the user to flexibly rotate the head. The center of gravity adjustment strap on the shoulder strap can be adjusted quickly to accurately position the center of gravity of the backpack. The waistband angle can be changed to ensure a comfortable carrying experience. The chest strap uses an adjustable design, which can adjust the distance between the shoulder straps according to the user's needs to enhance the stability of the backpack. The waist strap is composed of a waist pad and a waistband, and is formed by high-temperature molding. The foam material makes the waist pad soft and comfortable. The waistband adopts an adjustable angle movable webbing. The structure is a predetermined three-layer waistband, which can be adjusted according to the user's body type, so as to find the best bonding point and ensure its stable function. At the bottom of the backpack, a cross-type double webbing is used for support, which makes the combination of the backpack and the center of gravity of the person more stable.

In addition, the TCS is equipped with flexible double-sided support stabilizers on heavy-duty backpacks above 65L, which can stabilize the center of gravity of the backpack when the user passes through dangerous locations, and provide better weight distribution to enhance its stability.

#### *C. Ventilation function*

Ventilation device is one of the important criteria for the comfort of the suspension system. Outdoor explorers usually carry out for several hours, and a lot of sweat will be produced during the activity. At this time, the ventilation function of the carrying system is particularly important. A good ventilation function can improve the physiological comfort of the human body, including thermophysiological comfort, skin-sensing comfort, and ergonomic comfort, thereby increasing the carrying time [9].

The design of the ventilation structure in the system should be adjusted according to the external environment and the internal heat dissipation of the human body [10]. In the design of the ventilation device, the TCS mainly considers the reasonable distribution of the back cushion, the back cushion fabric and the concave-convex curvature design.

Regarding the distribution of back cushions, the TCS will thicken the back cushions at the junction of the shoulders and the back. The back cushions are designed as a trapezoid shape with a wide upper and a narrow lower back according to the distribution of the human back muscles. An adjustable thicker cushion is designed at the fulcrum, and the entire back cushion forms a saddle-like structure in both vertical and horizontal directions. While solving the gravity distribution, a good ventilation cycle is achieved.

In terms of fabric selection, the thickened back cushion of the TCS is filled with polyethylene foamed cotton, and the surface is 3D breathable mesh. This kind of mesh structure fabric has a good ventilation effect.

In the concave-convex structure, the TCS back cushion presents a concave structure on the upper back of the human body, so that a space for gas exchange between the backpack and the body is formed, which helps air circulation and ventilation. At the lumbar fulcrum, there is a convex structure, which fits the curvature of the body and provides support for the waist.

#### *D. Adjustable function*

Since the carrying system is developed from a fixed metal structure, it can only be applied to users of a certain height. The adjustable device is a necessary device designed to adapt to the individual differences of users and different carrying environments.

Generally, the adjustable device of the backpack system is divided into an up-regulation type and a down-regulation type. The upward adjustment refers to the design of stepped adjustment at the root of the shoulder strap; the downward adjustment refers to the design of an adjustment device on the waist pad.

The TCS suspension system breaks through the ordinary adjustment device, and innovatively designs the hidden EVA pad adjustable device behind the back plate. There is an adjustable EVA cushion hidden behind the back panel in the middle of the back. According to the length of the back of different bearers, there are four levels of S, M, L and XL adjustable. This simple adjustment device allows the user to slightly increase or decrease the waist. The length of the back can be increased or decreased according to the length of the user's back, so as to meet the needs of users of different heights. The specific adjustment method is: firstly, find the position of the hip bone, which is the protruding bone on the lower side of the waist; then determine the position of the C7 vertebra, as shown in Figure 2, the protruding bone at the back of the neck, and measure the C7 vertebra to the hip bone. The length of the center point is the length of the user's back; finally, the distance from the shoulder strap to the bottom of the backpack waistband is adjusted to be consistent with the length of the user's back, that is, the appropriate carrying length. This easy-to-operate structure can quickly adjust the length of the back.

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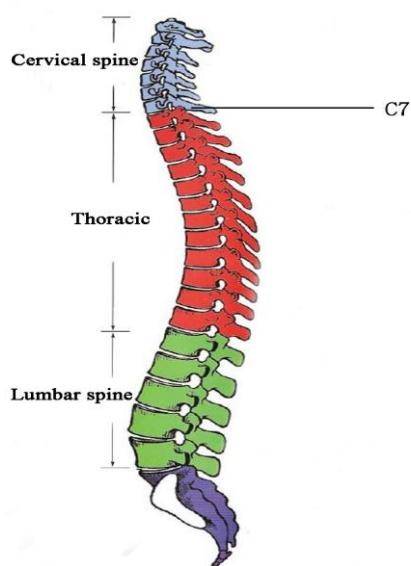


Fig.2 C7 vertebra schematic diagram.

addition, the TCS suspension system is designed with adjustable devices on the shoulder straps and top hat. The prefabricated foam plastic shoulder strap is designed with a retractable structure, which can be adjusted to fit the length of the back at any time; the height of the top hat can be adjusted, which can be used to adjust the capacity of the backpack, and the fastener can transfer the force of the shoulder to the core part. The user can use the angle of the fastener to adjust the backpack to a comfortable fit position, move the overall center of gravity forward, and maintain stability during travel.

#### IV. OUTDOOR BACKPACK STRUCTURE DESIGN

The TCS system enables users to have a comfortable backpack experience, mainly relying on its reasonable composite bracket design and highly breathable ventilated back pads. The outdoor backpack structure design is based on it, and through three aspects: the split structure design of the back panel, the ventilation structure design of the back cushion, and the structure design of the movable waist belt, further structural improvements are made to enhance the comfort of the TCS suspension system.

##### A. Design of split structure of backplane

The backboard design of outdoor backpacks is mainly to allow gravity to be distributed on the human body reasonably. The general sequence of carrying gravity transmission is: shoulders-waist-hips-feet. Through the structural design of the split back plate, the weight of the back is mainly transferred to the waist. Using the waist as the main load-bearing part can remove unnecessary load-bearing transmission, thereby reducing physical exertion. Good gravity distribution should

reduce the load-bearing of the shoulders, and distribute part of the weight of the shoulders to the clavicle and scapula, so that the shoulders are used as auxiliary load-bearing parts.

The backboard of the TCS is mainly divided into two parts, the back and the waist, which are in a trapezoidal structure with a wide upper part and a narrow lower part. In a few styles, the back panel is divided into upper and lower parts to facilitate the adjustment of the back panel. As shown in Figure 3.

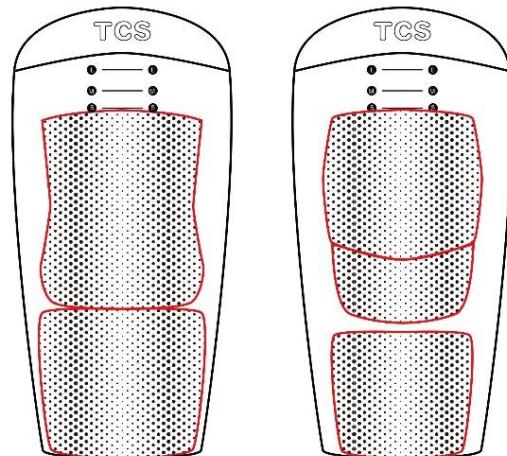


Fig.3 TCS backplane segmentation

The human back is composed of the spine, spinal cord, spinal nerves and spinal supporting muscles. The trunk muscles include cervical extensor, latissimus dorsi, trapezius and erector spinae. Through the human body surface EMG collection test, when carrying out weight-bearing exercise, the male trapezius muscle fatigue is significant, and the female neck extensor fatigue is significant, but the pressure on the latissimus dorsi is relatively small [11]. Therefore, on the basis of the backplane segmentation of the TCS, the distribution of the human spine and back muscles should be considered, and the "meter"-shaped segmentation should be performed to make it more suitable for the trapezius and scapular muscles, and the curvature of the backplane It should be convex in the back and slightly concave on both sides, in line with the direction of the muscles, and improve the covering of the backboard, so as to further disperse gravity.

In addition, it is possible to divide the plate at the waist and further divide it. The erector spinae, which connects the sacrum and the occiput, supports the movement of the spine, is one of the muscles that are prone to strain during the activities of the lower back. The erector spinae and thoracolumbar fascia are in the shape of an inverted triangle in the waist area, and the spine is concave toward the front of the human body. Supporting the waist during the weight-bearing process can effectively reduce muscle fatigue. The lumbar backplane is divided longitudinally, the curvature is convex, and the adjustment device is added behind the back cushion to freely adjust the curvature, thereby reducing the burden on the back pressure.

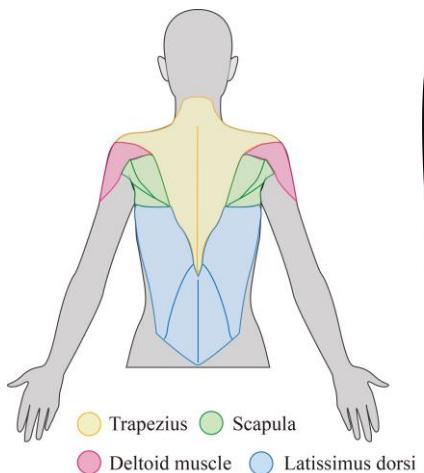


Fig.4 Backplane partition structure design

The improved design of backplane segmentation based on the TCS is shown in Figure 4.

#### B. Back cushion ventilation structure design

Human body generates a lot of heat during outdoor activities. The environmental temperature, wind speed and humidity are the main factors that affect the stability of the heat dissipation of the human body [12]. The shoulders, back and waist are often the main areas for heat dissipation and perspiration during climbing. Therefore, in the ventilation structure design of outdoor backpacks, a certain gap must be formed between the body and the backpack, air can circulate and promote heat dissipation.

The ventilation structure is to use 3D mesh fabrics in the contact area between the backpack and body, such as the shoulders, back, and waist. The three-dimensionality of the hole-like structure can prevent the human body from adhering to the backpack, forming a ventilated space to achieve good gas circulation. The structure means that the back pad, waist belt and shoulder straps are filled with polyethylene foam. The foam material has good air permeability and can keep the shoulders dry.

When carrying exercises, the trapezius muscles of the shoulder and neck fit the backpack most closely. Therefore, the soft cushion is designed to be thin in the front and thick in the back to improve the heat dissipation and ventilation of the shoulders. The back is the area with the largest perspiration area during the exercise. In the back cushion, design diagonal ventilation slots with different angles according to the direction of human muscles, and 3 ventilation slots on the left and right sides are symmetrically distributed to ensure air circulation and human comfort; the waist cushion and back cushion are similarly designed with two symmetrical diagonal ventilation slots on the left and right.

The back cushion ventilation structure design based on the TCS suspension system is shown in Figure 5.

#### C. Structure design of movable belt

The waistband part of the system is the key part to ensure the fit and stability of the human body. It is also the part with a large range of movement during the backpack movement.

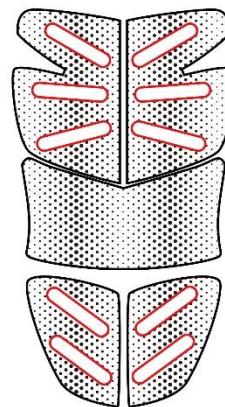


Fig.5 Backplane ventilation structure design

Therefore, the flexibility of the waistband plays an important role in the overall comfort of the backpack.

The waist belt structure of the TCS is not designed to be divided, only the horizontal groove structure is designed inside the thickened cushion of the waist belt to achieve the purpose of ventilation. This structure will form certain wrinkles when the human body performs activities such as waist rotation and bending, which affects sports comfort and flexibility.

Based on the TCS system, the waist belt is designed as a fin-shaped curve structure, which can improve the flexibility of the waist belt. The curved structure waist belt structure can ensure the stability and comfort of the load, and transfer the weight of the backpack to the core part of the waist, which can reduce the friction between the waist and legs during the long-time load-bearing process. The flexible curved belt can also make waist and shoulder movements more coordinated. In addition, the upper part of the fin-shaped curve segment is filled with multiple layers of compressed cotton. The composite layer is composed of comfortable elastic cotton, load transfer cotton, core weight transfer layer and stable shell from the inside to the outside to provide maximum comfort at the waist.

The structure design of the movable belt based on the TCS suspension system is shown in Figure 6.

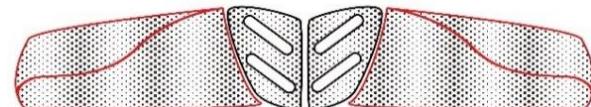


Fig.6 Movable belt structure design

## V. CONCLUSION

Through the research on the lightweight function, stabilization function, ventilation function and adjustable function of the TCS suspension system, the structure design and fabric selection are explored. And on this basis, carry out the design of the split structure of the back panel of the backpack system, the ventilation structure of the back cushion and the structure of the movable waist belt.

The TCS suspension system is a more comprehensive carrying system among the current large-capacity backpacks, which can meet the multi-functional needs of the backpackers. The structural design on this basis further improves the system,

which has important reference value and research significance in outdoor backpack design.

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