RESEARCH ARTICLE

Novel Structural Design of a Bicycle Saddle to Fulfill Cyclist Physiological Requirements

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Abstract: Background: The perineum area that interacts with the saddle is vulnerable; compressing neurovascular tissues has been asserted as the link to pathologies. Existing saddle designs are mainly based on the hole blocks, which are composed of two materials. These composite combined structures increase manufacturing difficulty.

Objective: The injection molding technology is suitable for mass production. We proposed a saddle design to meet the ergonomic requirements of cyclists. Saddle frames present a continuous curvature geometry to ensure improved injection modeling.

Methods: Static numerical calculations and measurements were employed for vertical load evaluations with different stiffness regions acquired using perforated chain patterns. Two-step plastic injection molding was utilized with proper bonding and processing compatibility. In prototyping, the first and second shots are PC and TPE, respectively.

Results: The frame sustains vertical loadings from bending and provides adequate stiffness and proper flexibility. The computer-aided design mold increases the contact area, and annular grooves increase the adhesion between two materials. The outer frame exhibits high rigidity; the middle area exhibits flexibility and high deformation.

Conclusion: This question is widely noticed and various answers have been proposed. By investigating the patent database and searching journal papers on saddle designs, the authors confirmed the novelty of the proposed structure.

Keywords: Bicycle saddle, structural design, cyclist needs, patent analysis, physiological requirements, novel structure.

1. INTRODUCTION

A cyclist uses a bicycle for sports and recreation. The cycling sport includes professional and amateur races, which are mostly held in continental Europe, the United States, and Asia. Road bicycle racing involves both team and individual competitions and involves contests of various manners, from the 1-day road race to multi-stage events such as the Tour de France [1]. In addition to the efficiency consideration, cycle design should emphasize human safety, comfort, and health. In the design, human factors must be considered to reflect requirements. Many types of bicycles exist for leisure, mobility, and sports purposes; these bicycles have different problems. The parameters of bicycle components must be adjusted according to use modes to ensure efficiency and humanization. This paper focused on the improvements of sports bicycles.

1.1. Requirements of Cyclists

A bike saddle can be considerably uncomfortable because of soreness caused by contact with the seat. This discomfort occurs in sit bones or in the area between the anus and genitals. A certain amount of pain is inevitable with long days of cycling. A combination of pressure bearing down on the saddle, friction from the constant pedaling motion, and blood flow compression can cause sores [2]. Bicycle riding-associated traumatic injuries have been documented. The prevalence of nontraumatic bicycle injuries can be as high as 85%, including knee, neck/shoulder, hands, buttok, and perineum injuries [3]. The male anatomy may influence saddle pressure [4]. For women, a statistical difference was found between trunk positions for a saddle with a cut-out.

When a bicycle is ridden over an uneven road, long-term vibrations often cause considerable discomfort to the rider. The seat receives the weight of the human body, and most of the impact force is transmitted to the user. Therefore, the saddle design highly influences riding comfort. The tradi-
tional seat widely uses a metal spring coil between a cushion and frame to absorb the vibration impact. However, metal spring coils present the disadvantages of less damping and stress concentration. Noise can be generated during the expansion and compression of bumps. Moreover, metal spring coils are heavy and cannot meet the requirement of the rider’s weight reduction. Cyclists await for a comfortable saddle design with satisfactory shock absorption [5].

1.2 Ergonomics and Mechanics

When sitting normally, sit bones support the body weight and can withstand high pressure. In an athletic riding position, the perineal area of men and the lower positioned pubic bone arch of women rest on the saddle. The network of nerves and blood vessels of the perineal area reaches pubic bones. In the dynamic riding position, the buttocks contact point moves from the tip of the sit bones and moves along the pubic arch to the pubic bone and central perineal area. The pressure is distributed on sit and pubic bones [5].

The comfort of bicycle riding is closely related to the body size and vehicle type. Experiments were performed by adjusting frames to simulate the actual riding resistance. Considerable differences were observed in the occurrence points of pressure peaks for different vehicle types and body sizes [6]. Factors that affect the length of the crotch area of the seat are the human weight and height of the seat handle. Factors affecting the size of the ischial area of the seat include the rotor height, the torso length, the weight, and the relative height of the seat handle. Selecting an accurate saddle can reduce the damage caused by riding.

Both materials and construction are related to riding comfort. Generally, a bicycle saddle is placed on a base composed of a hard material and is provided with a buffer body composed of foam. The cushion body is considerably soft and can only slightly relieve riding pressure; however, hips are still hard. Moreover, in bicycles, hard materials are used to form a saddle, which can sometimes increase discomfort.

A saddle is composed of three parts, namely a hard inner shell at the bottom, a middle layer of foam on the inner shell, and a cloth or leather surface covering the middle layer. Another cushioning element is the shock-absorbing structure between the saddle and seat post of the bicycle. The middle layer is elastic foam; the bottom shell supports the middle layer and serves as a base for the cushion. In the early days, the inner shell was composed of a metal, but nowadays, it is mostly composed of hard plastic. Because of the high hardness of the saddle-shaped inner shell, riding a bicycle for a long time, even with foam on the top, is uncomfortable. A combination of soft and hard materials can be achieved by removing some hard materials and filling layered elastomers. The inner edge of the hollow part must be connected with the riding frame; otherwise, it separates from the main seat body through cracking after a long time.

2. MATERIALS AND METHODS

2.1. Bicycle Saddle Design

The saddle design highly reduces the symptoms and problems of pubic pain. During a 2-h laboratory ride, the average score obtained using a typical saddle was considerably low [7]. Another study compared a nonprotruding nose with a traditional narrow nose. A narrow protruding nose appears to be justified to reduce pressure on the perineum [8]. The load measured on pedals and handlebars showed no difference between a traditional saddle and a saddle with no protruding nose.

For a sample with the weight, height, and average age of 65 kg, 175 cm, and 21.6 years, respectively, the average distance of the maximum pressure point tested was 12.4 cm, and the standard deviation was 1.5 cm. An ischial tuberosity is the point of maximum pressure on a flat saddle surface. In our design, we provided the most extensive possible variation, which covered a large area of contact.

2.1.1. Concept Design

Fig. (1) presents the pressure-releasable bicycle saddle cushion equipped with a virtual central axis, which separates the saddle cushion into three parts: the perineum (pubic bone) region, the left ischial part, and the right ischial part with supports. The support surface at the perineal (pubic) site is parallel to the virtual axis; the support surface at left and right ischial sites forms an angle of 45°-75° with the axis. Fig. (2). The support area is arranged close to the direction of main vessel flow, which reduces the obstruction of blood flow; it can provide deflection and ventilation when deformations are small. The saddle can be produced using injection molding. This gap between 2 parts offers stability under hip pressure. The adjustable support size and angle increase the friction to improve ride maneuverability.

![Fig. (1). Explored view of the proposed saddle structure, where 10a is the outer frame, 12a is the edge area, 20a is the pressure-releasable web structure, 16a is saddle supporter, and 101a is the nose area.](image-url)
From the side view, the extent of the bending of the frame appears relatively low. The seating area remains unchanged after deformation. Fig. (3) reveals that the surface of the area between IT and the front area is slightly convex (almost flat). Moreover, flat areas reduce shear stress. During riding without separation, the saddle does not cause further compression in the seating area. This design considerably improves manufacturability problems. Further experiments were performed to validate the proposed model.

2.1.2. Numerical Simulations

Lin [9] proposed a wheelchair cushion that can be adapted to the contour shape of individual hips. It comprises 361 adjustable cylinders with a diameter and spacing of 1.5 and 2 cm, respectively. The effect of stress dispersion was analyzed using the finite elements method. The model contains hip bones, soft tissue, and a cushioned support cylinder and has 17,431 nodes and 8,730 elements. A displacement of 11.17 mm applied above the bones shows that the pressure of the hips of the saddle cushion is 15 KPa.

Many relevant strategies have been proposed. The computational aspects of Galerkin’s approximation were studied [10] using continuous piecewise polynomial basis functions. The computation of fractional directional derivatives on triangular elements was enhanced; that is, a realistic finite element model was used for a rational optimum plastic design. Limit and shakedown loads were obtained for a square plate with a hole and for a thin tube [11] and were compared with known analytic solutions. In another study [12], authors optimized shapes for enhancing structural properties to verify the combination of optimal structural features and shape appearance.

Although we constructed a complete digital model by using CATIA, we utilized strategies in areas where a detailed acting model of the stress was required; otherwise, we employed the simplified geometries in less stressful areas. Deformations were calculated through static analysis to validate the experimental results. Parameters or boundary conditions must be adjusted iteratively. After the model was validated, an engineer changed the geometry or properties to achieve the design goal.

To reduce the computation time, the advanced size functions were set as follows: the curvature in the “relevance center” was “coarse”; the minimum mesh size was 0.12 mm. An ANSYS package simulated the vertical static loads applied to the saddle. Fig. (3) presents the results of the static analysis, and the largest deformation is located around the applied load regions. Compared with continuous shell-type saddle, the surface between ITs (ischial tuberosities) does not bend into larger curvature surfaces.

2.1.3. Measurement and Observations

A two-material plastic is fabricated by injecting two plastics into the same mold. The mold has two barrels, and each barrel has its own channel and nozzle, which control the order of the plasticized melt into the nozzle. The selected materials should satisfy the requirements of bonding and processing compatibility. In our case, soft and hard plastics were used to inject the hard part of the product first and then inject the soft part of the product. The first shot has a high melting point temperature, and the second shot is a softer TPE (Thermoplastic elastomers); the computer-aided design mold increases the contact area of the outer frame, and an annular groove increases the adhesion between the materials. Fig. (4a) shows the long and narrow cushion surrounded by a rigid frame, and its inside is a porous pattern that forms the loading area. A total of two strip-shaped stainless steel support frames are placed on the back of the seat cushion, which are used to connect the cushion with the bicycle body. We inspected the completed sample and pressed the outer frame to determine rigidity; the middle-hole area was flexible, and the part contacting with organs exhibited considerable deformation.

The force applied on a traditional saddle passes from the center to either side; the force causes the formation of a sharp convex surface, thereby pushing the ischial tuberosity outward. When the saddle is poorly supported, the nose turns relatively upward after deformation, which increases the pressure on organs (Fig. 4b). The surface material is soft and provides ventilation; the edge area is harder and can with-
stand acceleration and pressure. By using various combinations and two sets of molding fixtures, costs can be reduced.

3. RESULTS AND DISCUSSION

To examine patent applications, establishing improved standards and principles to judge patent validity and industrial applicability is essential. Moreover, patentability requires novelty and nonobviousness. By comparing the differences, whether the solution was obvious to the technician was assessed, which is a common and crucial concern.

3.1. Industrial Applicability and Nonobviousness

The legal requirements for receiving patents are as follows: (a) Utility: The device should be useful or industrially applicable and should provide useful functionality. (b) Novelty: It must exhibit an aspect that is different from the previous invention up to the date. (c) Nonobvious: It must provide new and unexpected results. PHOSITA denotes a person of skill in a technical area. The skilled person can assess prior art and provide suggestions in a general technical field. In the United States patent law, utility is a patentability requirement [13]. As provided by 35 USC (United States Code) § 101, an invention is "useful" if it provides some identifiable benefits and can be used [14]. Furthermore, industrial applicability is related to the disclosure sufficiency requirement. The technical information of patent applicants must be sufficiently clear and complete for it to be carried out [15]. In re Clay, two criteria were evolved for determining whether the prior art is analogous: (1) whether the art is from the same field of endeavor, regardless of the problem addressed, and (2) if the reference is not from the field of the inventor's endeavor, whether the reference remains reasonably pertinent to the particular problem the inventor is involved with [16].

3.2. Investigation of Patent Database

We searched the patent database to verify if a previously developed seat design exhibited a similar structure. Because Taiwan is a vital region for bicycle production, many search results were found within Taiwan and U.S. patents database.

A bicycle saddle comprises the base formed of the main body and an elastic body. The main body is provided with a shock-absorbing area, which in turn is provided with numerous receiving spaces. Fig. (5) shows that each receiving space contains a shoulder portion located along the peripheral, such that the shoulder portion is beneath the top level of the shock-absorbing area. The elastic body is filled into the shock-absorbing area through molding.

The structural design includes two regions with different stiffness. The rigid plastic body comprises a hollowed-out area at the riding part, and the hollowed-out area is connected by a support rod to distinguish it from a hollow block Fig. (6). The elastomer filled through molding occupies the empty region and is connected to a whole cavity. The sunken area of the inner shell exhibits a staggering mix of soft elastomers with medium stiffness and hard braces.

In a "saddle cushion with dispersed pressure", a nose pad and tail pad are installed at the front and rear ends of the cushion, respectively, and the cover is set outside the body. Fig. (7) shows that a decompression accommodating space is available between nose and tail pads; the elastic body is placed in this space. The two sides of the flexible body pro-
trude from a chair. When the pressure applied by the rider squeezes and deforms the flexible body, the two elastic bodies protrude from the chair cover and support the rider’s genitals.

![Fig. (6). TW-542139 two regions with different stiffness [17], where 14 is the flexible cover, 23 is the hollowed-out area, and 27 is staggering elastomers.](image)

The main body of the cushion decompression structure has a narrow and wide shape and is composed of the hard material, and most of its rear part is developed as two symmetrical load areas. Fig. (8) shows both load areas are recessed, and multiple soft bumps are provided, each of which can be fitted. Numerous appropriately shaped recessed holes are available in this structure. The rear part of the main body is concave and gradually escalates from the middle to the edge. The elastic deformation occurring during loading can release pressure.

The saddle includes a base, a cushion body, a fixing device, and a buffer body. Fig. (9) shows that the buffer body is placed between the base and the pad (the central part bears the impact force) to lock the pad and base in different positions. The ethylene-vinyl acetate material properly adapts to the deformation of the rider’s hips with vibrations.

![Fig. (8). TW-I317710 Cross-section view of the replaceable part of the saddle [19], where 2 is the soft bump, and 10 is the rear part of the main body.](image)

![Fig. (9). TW-I376326 Exploded view of the cushion and fixing approach [20], where 11 is the base, 138 is the buffer body, and 111 is the lock pad.](image)
A capsule is hermetically wrapped between the body and cushion to provide cushioning. Fig. (10) shows a pill is compressed, leading to the deformation of the elastic material. The covering and elasticity provide airbag support, thus preventing excessive deformation and cushioning losses.

The body composed of a single material performs the required functions; thus, it is applicable in industries. This body does not exhibit the same structure compared with the bodies obtained from previous technologies. Traditional saddles are piled with hard and soft materials. The proposed design exhibits a repeating structure to form a hard and soft fabric.

3.3. Academic Studies on Saddle Design

Various bicycle saddle designs have been developed to improve comfortability and alleviate the risk of injury through a reduction in pressure at the perineum; the excessive pressure is reduced by modifying the local hardness or shape of the support by using the trial and error method. In saddle designs, heterogeneous materials or central trench structures with specific shapes are utilized. Although they provide support to ITs and reduce pressure on perineal soft tissues, these designs provide only partially successful results [22, 23].

A depression at the center of the saddle focuses on the support of posterior bony structures, thereby reducing loading in the perineal region. However, depression cannot increase blood flow, which is substantially limited by perineal compression [24]. The presence of depression at the center of the saddle is not directly related to pressure reduction. A fuller saddle without a nose causes stability support loss and reduces bicycle maneuverability during high-intensity riding [25]. These findings indicate that extrinsic factors in saddle design include not only normal surface pressure but also shear forces, friction, temperature (heat dissipation), and moisture-related injuries. Friction must provide sufficient grip for stability during cycling. Most people select a saddle with a protruding nose for high comfort and performance.

Pressure distribution can be resolved by modifying the local hardness of the support based on pressure-sensitive mats. However, this chamois style design is not practical for mass production. Redistributing pressure by padding the saddle with soft material can satisfy a part of the generalized requirements.

Sequenzia [26] proposed a variable geometry saddle prototype. Fig. (11) shows the rider can adjust nose inclination and the width of the saddleback with less time delay. The chamois design can reduce the mean peak saddle pressure and increase the perceived comfortability during cycling for
men and women. The relationship between perceived satisfaction and the mean peak saddle pressure considerably varies within and between genders [27]. An adjustable mechanism may cause injury and may be unclear to users without guidance.

CONCLUSION

The nonplanar structure of the proposed design includes support facets and vertical arch ribs connecting the facets. The proposed design matches the bending flexibility of the support surface and arch ribs with shear stiffness under a load perpendicular to the saddle-shaped surface. People with ordinary knowledge of the technical field cannot easily use a single manufacturing process to complete a single-material bicycle mat with two rigidities. Racing bicycles are lightweight because competitors want to use limited weight to meet their physical requirements; thus, substantially large and heavy components are usually unacceptable in these bicycles. The provided patents or studies have used multiple materials for the design. Therefore, those with ordinary knowledge of the art cannot practically use a combination of different forms, holes, and materials to accommodate the pelvis with comfort; the design of a bicycle pad fabricated using a single manufacturing process is not obvious.

This question is widely noticed and various answers have been proposed. The suitable form needs to be determined according to the use situation and individual size. On the saddle surface, the structure supports vertical loads through a web-like flexure. The contact surface is highly suitable for riding loads. Notches and grooves provide sliding friction during dynamic riding, which enhances body stability during cycling. Recently, children’s scooters have become popular, and the use of this special type of saddle needs further evaluation.

CURRENT & FUTURE DEVELOPMENTS

The authors addressed the importance of a two-step molding on the future saddle design. The different plastics properties can trigger the need for specific toughness and softness.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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